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SOLAR EMISSIONS FROM GHz TO SUB-THz FREQUENCIES

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14. ABSTRACT
The resources allowed unprecedented simultaneous solar observations with the 45 and 90 GHz polarimeters, the 0.2 and 0.4 THz solar telescope (SST), and the 30 THz detector (10 um band), installed and operated at El Leoncito, Argentina Andes. Another 30 THz telescope was installed at São Paulo. New discoveries arose from these observations, compared to data at other energy ranges, radio, visible, UV, soft and hard X-rays. Spectral properties were found in GHz to sub-THz frequencies. Discovery of the importance sub-THz pulsations association to a CME launch time long before a very large flare. Similarities between solar flare particle accelerators to laboratory high energy accelerators have been proposed. A plasma oscillating mechanism explained the sub-second pulses repetition rates proportionality to mean fluxes observed in a impulsive sub-THz burst. Discovery of new intense 30 THz impulsive burst correlated to white-light flare, hard X-rays, Ha, UV and other radio emissions. The grant provided helpful complementary research and development for the completion of next generation of solar flare THz detectors, including the integration and final tests of the 3 and 7 THz solar flare photometers SOLAR-T space experiment, and the ground-based 0.85 and 1.7 THz telescop

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SOLAR EMISSIONS FROM GHz TO SUB-THz FREQUENCIES

Abstract: The resources represented an essential support to unprecedented simultaneous solar observations with the 45 and 90 GHz polarimeters, the 0.2 and 0.4 THz multiple beam solar telescope (SST), and the 30 THz microbolometer array detector (10 µm band), installed and operated at El Leoncito, Argentina Andes. Another 30 THz telescope was recently installed at São Paulo. New discoveries arose from these observations, compared to data obtained at other energy ranges, radio, visible, UV, soft and hard X-rays. Detailed spectral properties were found in the GHz to sub-THz range of frequencies; it has been discovered the importance sub-THz pulsations occurring in association to the CME launch time long before a very large flare. Possible similarities between solar flare particle accelerators to laboratory high energy accelerators have been proposed. A new plasma oscillating mechanism has been proposed for the sub-second pulses repetition rates proportionality to the mean fluxes observed in a strong impulsive sub-THz burst. The program led to the discovery of new intense 30 THz impulsive burst correlated to white-light flare, hard X-rays, Hα, UV and other radio emissions. The grant provided helpful complementary research and development for the completion of next generation of solar flare THz detectors, including the integration and final tests of the 3 and 7 THz solar flare photometers SOLAR-T space experiment, and the ground-based 0.85 and 1.7 THz telescope. Ten papers published and three submitted.

INTRODUCTION:

The grant received from AFOSR represented an essential complementary support to ground- and space-based observations in the last unexplored wavelength frontier for solar flares is in the range of millimeter, submillimeter and infrared wavelengths. Although the central focus of the activities were on the description of solar activity at GHz, sub-THz and THz frequencies, it was analyzed their relationships to observations obtained at other radio, visible and higher UV, X- and gamma-ray energy frequency ranges, attempting to find new clues to understand the processes of energy build up and explosive release in active regions. A new 30 THz impulsive solar flare was discovered. It has been characterized the association of sub-THz pulsations to CME launch time well before a large flare. Sub-second flare sub-THz pulsations rates proportional to fluxes have been interpreted by a newly suggested plasma mechanism. The solar burst double spectral feature, from GHz to sub-THz and THz frequencies has been interpreted as similar processes found in laboratory accelerators.

The activities included observations in current Solar Cycle 24, from 2012-2015, maintaining, upgrading ongoing programs (i.e. the SST 0.2 and 0.4 THz solar telescope and the 30 THz telescope at El Leoncito, Argentina Andes) and implementing new experimental activities (the new 45 and 90 GHz solar polarimeters installed at El Leoncito, and another 30 THz telescope installed in São Paulo University's campus). Grant also supported partially new research and developments on THz detecting sensors, filters, materials and integrated systems for the completion of a 3 and 7 THz photometers experiment to be flown in a long duration stratospheric balloon mission, named SOLAR-T in 2015-2016, and the construction of a ground based 0.85 and 1.4 THz telescope (HATS) to be installed on high altitude site later in 2015.

We report the instruments, observations, and principal results obtained with the partial support of the AFOSR grant.

SUMMARY:

A) Instruments and Observations

1. Observations with the solar submillimeter-wave telescope (SST)
2. Progresses on SST data visualization upgrade and remote website access
3. The new 45 and 90 GHz solar polarimeters
4. SST and 45-90 GHz burst catalogue
5. Observations with the 30 THz (10 μm) and Hα telescopes
6. Solar Flare 3 and 7 THz Measurements from Space (SOLAR-T)
7. The 0.85 and 1.7 THz ground-based HATS telescope

B) Results:

- Papers published and abstracts

C) Illustrations:

- Recent presentations

A) INSTRUMENTS AND OBSERVATIONS

1. Observations with the solar submillimeter-wave telescope (SST)

There were major repair jobs on the SST related equipments mostly during 2013: (a) replacement of four driving motors of the SST positioner; (b) Replacement and adjustments of the 405 GHz radiometer. Job (a) was done. Job (b) was accomplished with the addition of new 405 GHz radiometers made by RPG, Germany, and successful re-installation done by El Leoncito engineers.

2. Progresses on SST data Visualization Upgrade and Remote Website access

Further improvements have been obtained for SST data visualization and remote access by Internet. It simplifies the visualization, at a considerably shorter time. One of CRAAM senior researcher has visited the El Leoncito facilities, to discuss further implementation of the softwares utilized at both ends, at El Leoncito and at the mirror site at CRAAM, Mackenzie. This work is being developed with the participation of professors of the Faculty of Computing and Informatics from Mackenzie Presbyterian University.

The SST visualization data can de accessed at:

www.casleo.gov.ar/sst/sst.php

3. The new 45 and 90 GHz solar polarimeters

Two circular polarization solar radio telescopes, named POEMAS, were installed at El Leoncito later in 2011 for observations of the Sun at 45 and 90 GHz. The novel characteristic of these instruments is the capability to measure circular right- and left-hand polarizations at these high frequencies. The two frequencies were chosen so as to bridge the gap at radio frequencies between 18 GHz (the higher RSTN frequency) and 200 GHz (the lower SST frequency) of solar flare spectra. The telescopes observe the full disk of the Sun with a half power beam widths of 1.4°, a time resolution of 10 ms at both frequencies, a sensitivity of 4 and and 20 solar flux unit at 45 and 90 GHz, respectively.

4. SST and 45-90 GHz burst catalogue

A program has started by carefully reviewing in detail all SST observations to produce the first catalogue of bursts well detected at 212 and at 405 GHz. The catalogue has been completed for the period 2012-2013, to which it has been added the bursts observed by the new 45 and 90 GHz solar polarimeters. The catalogue editing is in final phase. It contains about 50 bursts detected with the 45 and 90 GHz solar polarimeters, to which about 20 burst were well detected by SST.

This program will be extended for SST burst observed since 2006, with possible extension to earlier years, at least until 2002, when well corrected data can be retrieved.

5. Observations with the 30 THz (10 um) and Hα telescopes

Observations were carried at EI Leoncito during selected campaigns with the FLIR AM20 mid-IR (30 THz) camera with 160 x 120 pixels FPA and the Hα telescopes. Another optical setup has been installed replacing the aperture by a 15 cm concave reflector (Fig. 1). Several bursts were observed simultaneously together with SST and, since November 2011, with the two new solar polarimeters, at 45 and 90 GHz, being operated al EI Leoncito.

A new 30 THz solar telescope was added, recently installed in São Paulo, at the CRAAM laboratory, Mackenzie campus. It operates in conjunction with high cadence Hα observations. It uses 20 cm flat mirrors coelostat in Hale type configuration, projecting the solar radiation into a concave mirror in 15 cm Newtonian configuration. It utilizes a Wuhan Guide IR928 camera, with one ULIS microbolometer array of 640 x 480 pixels and germanium lens. The field of view sees the whole Sun, with thermal sensitivity of 0.08 K on snapshots images, allowing high frame cadence rates up to 30/second.

6. Solar Flare 3 and 7 THz Measurements from Space (SOLAR-T)

3 and 7 THz photometers double telescopes, designed for flare observations from above the atmosphere, named SOLAR-T, were completed built and tested in 2012-2015. The SOLAR-T has been coupled to the UC Berkeley, SSL, gamma-ray experiment GRIPS, to be flown on board of a NASA stratospheric balloon on a long-

duration mission (30 days) over Antarctica. First phase of integration has been accomplished at SSL, in July 2014. The entire assembly SOLAR-T & GRIPS were submitted to space simulations at NASA Glenn Plum Brook thermo-vacuum chamber, March 2015). The balloon flight is planned for a flight on souther hemisphere summer, 2015-2016.

7. The 0.85 and 1.7 THz ground-based HATS telescope

An innovative THz photometric telescope has been recently completed to operate from the ground, (named HATS for "**H**igh **A**ltitude **T**erahertz **Solar** photometers") at the atmospheric "windows" centered at .85 THz and 1.4 THz,at a selected high altitude location (>5000m). The HATS utilizes the same concept and technologies that led to the space SOLAR-T solar flare THz photometers experiment recently completed. Preliminary estimates for HATS 46 cm telescope performance, at moderately good zenith transmission at the 0.85 THz and 1.4 THz bands, predicts a 3 sigma burst detection level of 50 and 220 SFU, respectively.

B) RESULTS

Abstracts of papers published and submitted (credits given to AFOSR)

1. Kaufmann, P. "Observations of solar flares from GHz to THz frequencies". *Astrophysical and Space Science,* **30**, 61-71, 2012.

Abstract: The discovery of a new solar burst spectral component with sub- THz fluxes increasing with frequency, simultaneous but separated from the well-known microwave component, brings serious constraints for interpretation. Suggested explanations are briefly reviewed. They are inconclusive indicating that further progresses on the understanting of nature of the emission mechanisms involved require the knowledge of GHz to THz continuum burst spectral shapes. New 45 and 90 GHz high sensitivity solar polarimeters are being installed at EI Leoncito high altitude observatory, where sub-THz (0.2 and 0.4 THz) solar flare flux data are being obtained regularly since several years. Solar flare THz photometry in the continuum should be carried in space or at few selected frequency windows at exceptional ground-based sites. A 3 and 7 THz dual photometer system is being constructed to be flown in a long duration stratospheric balloon flight in Antarctica (summer 2013-2014) in cooperation with University of California, Berkeley, together with GRIPS experiment. One test flight is planned for the fall 2012 in USA. Another long duration balloon flight over Russia is considered (2015-2016), in a cooperation with Moscow Lebedev Physics Institute.

2. Kaufmann, P.; Holman, G.D.; Su, Y.; Giménez de Castro, C.G.; Correia, E.; Fernandes, L.O.T.; Souza, R.V.; Marun, A.; Pereyra, P. "Unusual emissions at various energies prior to the impulsive phase of the large solar flare and coronal mass ejection of 4 November 2003". *Solar Physics,* **279**, 465-475, 2012.

Abstract. The November 4, 2003 GOES X28 flare, 19:40-19:50 UT, was the largest ever recorded in its class. It produced the first evidence of the two spectrally separated radio/far infrared emission components, one at microwaves and another in the THz range of frequencies. We analyzed the 20 minutes before the impulsive onset of this

event and found unusual activity at X-rays (RHESSI), at sub-THz frequencies (SST), at H-a (BBSO) and at microwaves (Itapetinga 7 GHz polarimeter, RSTN and OVSA). The unusual activity began at about 19 27 UT with a slow rise at 6-10 keV and the start of a precursor at 7 GHz. Pulsations at sub-THz became pronounced, exhibiting correlations with RHESSI 25-50 keV pulsations and similar pulsations at 7 GHz. All pulsations faded out as 2 impulsive bursts were detected at 100-300 keV and 7 GHz with peak at 19 34 UT. LASCO movie show a large CME which height-time diagram linear extrapolation to the solar surface correspond to the first H- a BBSO brightening, suggesting an approximate launch time at about 1934 UT, close to the time of occurrence of hard X-ray and microwave impulsive bursts and nearly 8 minutes before the onset of the large flare. The precursor impulsive events were located nearly 2 arc-minutes south of the following major flare location at the solar west limb, as indicated by SST pulses positions and images obtained by RHESSI and BBSO. The spatial and time emission description favor the known suggestion that often flares sit at one side of the centerline of material ejection. The unusual activity may represent the complex energy buildup mechanisms leading to the CME launch, quite distinct in time and space from the major flare that exploded afterwards.

3. Kaufmann, P.; White, S.M.; Freeland, S.L.; Marcon, R.; Fernandes, L.O.T.; Kudaka, A.S.; Souza, R.V.; Aballay, J.L.; Fernandez, G.; Godoy, R.; Marun, A.; Valio, A.; Raulin, J.-P.; Giménez de Castro, C.G. “A bright impulsive solar burst detected at 30 THz”. *Astrophysical Journal*, **768**, 134-143, 2013.

Abstract: Ground- and space-based observations of solar flares from radio wavelengths to gamma-rays have produced considerable insights but raised several unsolved controversies. The last unexplored wavelength frontier for solar flares is in the range of submillimeter and infrared wavelengths. Here we report the detection of an intense impulsive burst at 30 THz using a new imaging system. The 30 THz emission exhibited remarkable time coincidence with peaks observed at microwave, mm/submm, visible, EUV, and hard X-ray wavelengths. The emission location coincides with a very weak white-light feature, and is consistent with heating below the temperature minimum in the atmosphere. However, there are problems in attributing the heating to accelerated electrons. The peak 30 THz flux is several times larger than the usual microwave peak near 9 GHz, attributed to non-thermal electrons in the corona. The 30 THz emission could be consistent with an optically thick spectrum increasing from low to high frequencies. It might be part of the same spectral component found at sub-THz frequencies whose nature remainsmysterious. Further observations at these wavelengths will provide a new window for flare studies.

4. Valio, A.; Kaufmann, A.; Giménez de Castro, C.G.; Raulin, J.-P.; Fernandes, L.O.T.; Marun, A. “POlarization Emission of Millimeter Activity at the Sun (POEMAS): new circular polarization solar telescopes at two millimeter wavelength rangers”. *Solar Physics*, **283**, 651-665, 2013.

Abstract: We present a new system of two circular polarization solar radio telescopes, POEMAS, for observations of the Sun at 45 and 90 GHz. The novel characteristic of these instruments is the capability to measure circular right- and left-hand polarizations at these high frequencies. The two frequencies were chosen so as to bridge the gap at radio frequencies between 20 and 200 GHz of solar flare spectra. The telescopes, installed at CASLEO Observatory (Argentina), observe the full disk of the Sun with a

half power beam width of 1.4°, a time resolution of 10 ms at both frequencies, a sensitivity of 2 - 4 K that corresponds to 4 and 20 solar flux unit (=10^4 Jy), considering aperture efficiencies of 50±5 % and 75±8 % at 45 and 90 GHz, respectively. The telescope system saw first light in November 2011 and is satisfactorily operating daily since then. A few flares were observed and are presented here. The millimeter spectra of some flares are seen to rise toward higher frequencies, indicating the presence of a new spectral component distinct from the microwave one.

5. Kaufmann, P.; Marcon, R,; Abrantes, A.; Bortolucci, E.C.; Fernandes, L.O.T.; Kropotov, G.. I.; Kudaka, A.; Machado, N.; Marun, A.; Nikolaev, V.; Silva, Alexandre, Da Silva, C.; Timofeevsky, A. "THz photometers for solar flare obseevations from space". *Experimental Astronomy*, **34**, 579-598, 2014.

Abstract: The search for the still unrevealed spectral shape of the mysterious THz solar flare emissions is one of the current most challenging research issues. The concept, fabrication and performance of a double THz photometer system, named SOLAR-T, is presented. Its innovative optical setup allows observations of the full solar disk and the detection of small burst transients at the same time. The detecting system was constructed to observe solar flare THz emissions on board of stratospheric balloons. The system has been integrated to data acquisition and telemetry modules for this application. SOLAR-T uses two Golay cell detectors preceded by low-pass filters made of rough surface primary mirrors and membranes, 3 and 7 THz band-pass filters, and choppers. Its photometers can detect small solar bursts (tens of solar flux units) with sub second time resolution. Tests have been conducted to confirm the entire system performance, on ambient and low pressure and temperature conditions. An artificial Sun setup was developed to simulate performance on actual observations. The experiment is planned to be on board of two long-duration stratospheric balloon flights over Antarctica and Russia in 2014-2016.

6. Klopf, .M.J.; Kaufmann, P.; Raulin, J.-P.; Szpigel, S. "The contribution of microbunching instability to solar flare emission in the GHz to THz range of frequencies". *The Astrophysical Journal*, **791,** 31-41, 2014.

Abstract: Recent solar flare observations in the sub-THz range have provided evidence of a new spectral component with fluxes increasing for larger frequencies, separated from the well-known microwave emission that maximizes in the GHz range. Suggested interpretations explain the THz spectral component, but do not account for the simultaneous microwave component. We present a mechanism for producing the observed "double-spectra". Based on coherent enhancement of synchrotron emission at long wavelengths in laboratory accelerators, we consider how similar processes may occur within a solar flare. The instability known as microbunching arises from perturbations that produce electron beam density modulations, giving rise to broadband coherent synchrotron emission at wavelengths comparable to the characteristic size of the microbunch structure. The spectral intensity of this coherent synchrotron radiation (CSR) can far exceed that of the incoherent synchrotron radiation (ISR), which peaks at higher frequency, thus producing a double-peaked spectrum. Successful CSR simulations are shown to fit actual burst spectral observations, using typical flaring physical parameters and power-law energy distributions for the accelerated electrons. The simulations consider an energy threshold below which microbunching is not possible because of Coulomb repulsion. Only a small fraction of the radiating charges

accelerated to energies above the threshold is required to produce the microwave component observed for several events. The ISR/CSR mechanism can occur together with other emission processes producing the microwave component. It may bring an important contribution at microwaves at least for certain events where physical conditions for the occurrence of the ISR/CSR microbunching mechanism are possible.

7. Zaitsev, V.V.; Stepanov, A.V.; Kaufmann, P. "On the origin of pulsations of sub-THz emission from solar flares". *Solar Physics*, **289**, 2017-2033, 2014.

Abstract: We propose a model to explain fast pulsations in sub-THz emission from solar flares. The model is based on the approach of a flaring loop as an equivalent electric circuit and explains the pulse repetition rate, the high quality factor, $Q \geq 10^3$, small modulation depth, pulse synchronism at different frequencies, and the dependence of the pulse repetition rate on the emission flux, observed by Kaufmann *et al.* (2009, *Astrophys. J.* **697**, 420). We solved the non-linear equation for electric current oscillations using a Van der Pol method and found the steady-state value for the amplitude of the current oscillations. Using the pulse rate variation during the flare on 4 November 2003, we found a decrease of the electric current from 1.7×10^{12}A in the flare maximum to 4×10^{10}A just after the burst. Our model is consistent with the plasma mechanism of sub-THz emission suggested recently by Zaitsev, Stepanov, and Melnikov (2013, *Astron. Lett.* **39**, 650).

Full papers at international conference proceedings

8. Kaufmann, P.; Abrantes, A.; Bortolucci, E.C.; Correia, E.; Diniz, J.A.; Gernandez, G.; Fernandes, L.O.T.; Giménez de Castro, C.G.; Godoy, R.; Hurford, G.; Kudaka, A.S.; Lin, R.P.; Machado, N.; Makhmutov, V.S.; Marcon, R.; Marun, A.; Nicolaev, V.A.; Pereyra, P.; Raulin, J.-P.; da Silva, C.M.; Shih, A.; Stozkhov, Y.I.; Swart, J.W.; Timofeevsky, A.V.; Valio, A.; Villela, T.; zakia, M.B. "SOLAR-T: Terahertz photometers to observe slar flare emission on stratospheric ballon flights". *Proc. SPIE* **8442**, Space Telescopes and Instrumentation 2012: Optical, Infrared, and MIlimeter Wave, 84424L1-84424L-9 (September 21, 2012).

Abstract: A new solar flare spectral component has been found with intensities increasing for larger sub-THz frequencies, spectrally separated from the well known microwaves component, bringing challenging constraints for interpretation. Higher THz frequencies observations are needed to understand the nature of the mechanisms occurring in flares. A two frequency THz photometer system was developed to observe outside the terrestrial atmosphere on stratospheric balloons or satellites, or at exceptionally transparent ground stations. 76 mm diameter telescopes were designed to observe the whole solar disk detecting small relative changes in input temperature caused by flares at localized positions at 3 and 7 THz. Golay cell detectors are preceded by low-pass filters to suppress visible and near IR radiation, band-pass filters, and choppers. It can detect temperature variations smaller than 1 K with time resolution of a fraction of a second, corresponding to small burst intensities. The telescopes are being assembled in a thermal controlled box to which a data conditioning and acquisition unit is coupled. While all observations are stored on board, a telemetry system will forward solar activity compact data to the ground station. The experiment is planned to fly on board of long-duration stratospheric balloon flights some time in 2013-2015. One will

be coupled to the GRIPS gamma-ray experiment in cooperation with University of California, Berkeley, USA. One engineering flight will be flown in the USA, and a 2 weeks flight is planned over Antarctica in southern hemisphere summer. Another long duration stratospheric balloon flight over Russia (one week) is planned in cooperation with the Lebedev Physics Institute, Moscow, in northern hemisphere summer.

9. Kaufmann, P.; Fernandes, L.O.T.; Kudaka, A.S.; Marcon, R.; Bortolucci, E.C.; Machado, N.; Abrantes, A.; Nicolaev, V.; Timofeevsky, A.; Marun, A.. "The performance of THz Photometers for solar flare observations from space". In: *IMOC 2013 – International Microwave Optoelectronics Conference, SBMO/MTT-S*, Rio de Janeiro, August, 4-7, 2013. IEEEXplore 978-1-4799-1397, 2013.

Abstract: The performance of the double THz photometers system is presented. It is the first detection device conceived to observed solar flare THz emissions on board of stratospheric balloons. The system, named SOLAR-T, has been built, integrated to data acquisition and telemetry modules developed for this application, and tested. It utilizes two Golay cell detectors preceded by low-pass filters, 3 and 7 THz band-pass filters, and choppers. SOLAR-T photometers can detect relative temperature variations smaller than 1 K with sub second time resolution. It is intended to determine the still unrevealed spectral shape of the mysterious THz solar flares emissions. The experiment is planned to fly on board of two long-duration stratospheric balloon flights over Antarctica and Russia in 2014-2016.

10. Kaufmann, P. "Space and Ground-Based THz New Tools for Solar Flare Observations". *26th ISSTT* - International Symposium on Space Terahertz Technology. Harvard-Smithsonian, Cambridge, MA, USA, March 16-18, 2015.

Abstract: Recent sub-THz and 30 THz observations revealed an unexpected new spectral component, with fluxes increasing towards THz frequencies, simultaneously with the well known component peaking at microwaves, bringing challenging constraints for interpretation. The knowledge of the complete THz flare spectrum is the essential requirement for understanding the origin of this radiation. We present the concept, fabrication and performance of telescope photometric systems to observe solar flares at 3 and 7 THz from above the atmosphere, named SOLAR-T, and at 0.85 and 1.4 THz from the ground at a high altitude site, named HATS. The innovative optical setup allows observations of the full solar disk with high sensitivity to detect small burst transients (tens of solar flux units) with time resolution of less than one second. The SOLAR-T space experiment uses two Golay cell detectors at the focus of 7.6 cm Cassegrain telescopes. The incoming radiation undergoes low-pass filters made of rough surface primary mirrors and membranes, 3 and 7 THz band-pass filters, and choppers. The system has been integrated to data acquisition and telemetry modules for this application. Tests comprised the whole system performance, on ambient and low pressure and temperature conditions. SOLAR-T is being integrated to U.C. Berkeley gamma-ray GRIPS experiment to be flown on a long duration stratospheric balloon mission over Antarctica. The HATS telescope utilizes the same principles, with a 46 cm rough mirror Newtonian telescope, a Golay cell sensor preceded by low pass filter, and a double window chopper, each one with band pass filters at 0.87 and 1.4 THz. HATS

now undergoes operational tests in Brazil, and is planned for operations in 2015 at a site to be selected in the Andes Cordillera, above 5000 m altitude.

Papers submitted

11. Miteva, R.; Kaufmann, P.; Cabezas, D.P.; Fernandes, L.O.T.; Freeland, S.L.; Karlicky, M.; Kerdraon, A.; Kudaka, A.S.; Luoni, M.L.; Marcon, R.; Raulin, J.-P.; Trottet, G.; White, S.M. “30 THz impulsive burst observed during solar M2-class flare on 1 August 2014”. Submitted to *Astronomy & Astrophysics*, 2015.

Abstract: We report the detection of an intense 30 THz impulsive burst on 1 August 2014 associated with a GOES M2 class solar flare. The maximum flux at 30 THz was about 19000 sfu, almost two orders of magnitude larger than measured at microwave frequencies, and three orders of magnitude above the detection limit at sub-THz frequencies. A good correspondence between the temporal profiles and positions at 30 THz, EUV and H_ wavelengths was observed. The microwave emissions at higher frequencies exhibit a suggestive time association with the 30 THz peak. At the metric-to-decimetric frequency range a superimposed short duration burst occurs close to the peak of the 30 THz emission while the underlying slower emission maximum is progressively delayed for lower frequencies. The flaring source seen at EUV and H_ has finer spatial structures not resolved within the 30 THz 15 arc-seconds ‘photometric beam’. It is suggested that the 30 THz, EUV and Hα brightening originate from a common flaring site at the low chromosphere, consisting of a non-thermal faster component superimposed to thermal emission.

12. Kudaka, A.S.; Cassiano, M.M.; Marcon, R.; Cabezas, D.P.; Fernandes, L.O.T.; Hidalgo Ramirez, R.F.; Kaufmann, P.; Souza, R.V. “The new 30 THz solar telescope in São Paulo, Brazil”. Submitted to *Solar Physics*, 2015.

Abstract: It has been found that solar bursts exhibit one unexpected spectral component with fluxes increasing with frequency in the sub-THz range, distinct from the well-known microwave emission maximizing at few to tens of GHz. This component has been found to extend into the THz range of frequencies by recent 30 THz solar flare observations of impulsive bursts with flux intensities considerably larger than fluxes at sub-THz and microwaves frequencies. High cadence solar observations at 30 THz (continuum) are therefore an important tool for the study of active regions and flaring events. We report the recent installation of a new 30 THz solar telescope, located at the top of one of the University’s buildings. The instrument utilizes a Hale-type coelostat with two 20 cm diameter flat mirrors sending light to a 15 cm mirror Newtonian telescope. Radiation is directed to a room temperature microbolometer array camera. Observations are usually obtained with 5 frames/s cadence. One 60 mm Hα refractor has been added to observe simultaneously. We describe the new observatory giving examples of the first results obtained.

13. Kaufmann, P.; White, S.M.; Marcon, R.; Kudaka, A.S.; Cabezas, D.P.; Cassiano, M.M.; Francile, C.; Fernandes, L.O.T.; Hidalgo Ramirez, R.F.; Luoni, M.; Marun, A.; Pereyra, P.; Souza, R.V. “Bright 30 THz impulsive solar bursts”. Submitted to *J. Geophys. Res. – Space Phys.*, 2015.

Abstract: Impulsive 30 THz continuum bursts have been recently observed in solar flares, utilizing small telescopes with a unique and relatively simple optical setup concept. The most intense burst was observed together with a GOES X2 class event on October 27, 2014, also detected at two sub-THz frequencies, RHESSI X-rays and SDO/HMI and EUV. It exhibits strikingly good correlation in time and in space with white light flare emission. It is likely that this association may prove to be very common. All three 30 THz events recently observed exhibited intense fluxes in the range of 10^4 solar flux units, considerably larger than those measured for the same events at microwave and sub-mm wavelengths. The 30 THz burst emission might be part of the same spectral burst component found at sub-THz frequencies. The 30 THz solar bursts open a promising new window for the study of flares at their origin.

C) ILLUSTRATIONS

Attached are PDF copies of recent presentations at AFRL Space Science Review Program (Abuquerque, NM, January 2015) and at 26th ISSTT (Cambridge, MA, March 2015), that give illustrations o the equipments mentioned and results.

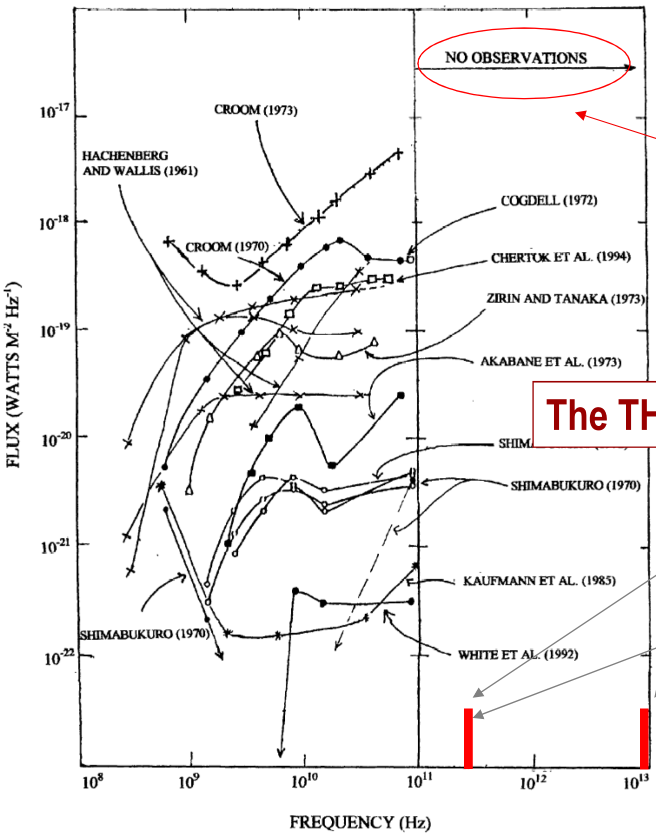
AFOSR Space Science Review, 14-16 January 2015

SOLAR EMISSIONS FROM GHz TO THz FREQUENCIES

Pierre Kaufmann
Universidade Presbiteriana Mackenzie
São Paulo, SP. Brazil

Funding agencies:

SOLAR BURSTS SPECTRA AT HIGHER FREQUENCIES AS KNOWN IN PAST CENTURY



DIFFERENT FLARE EMISSION MECHANISMS MAY FIT INTO THIS UNKNOWN SPECTRAL RANGE

The THz observational gap

First tries:

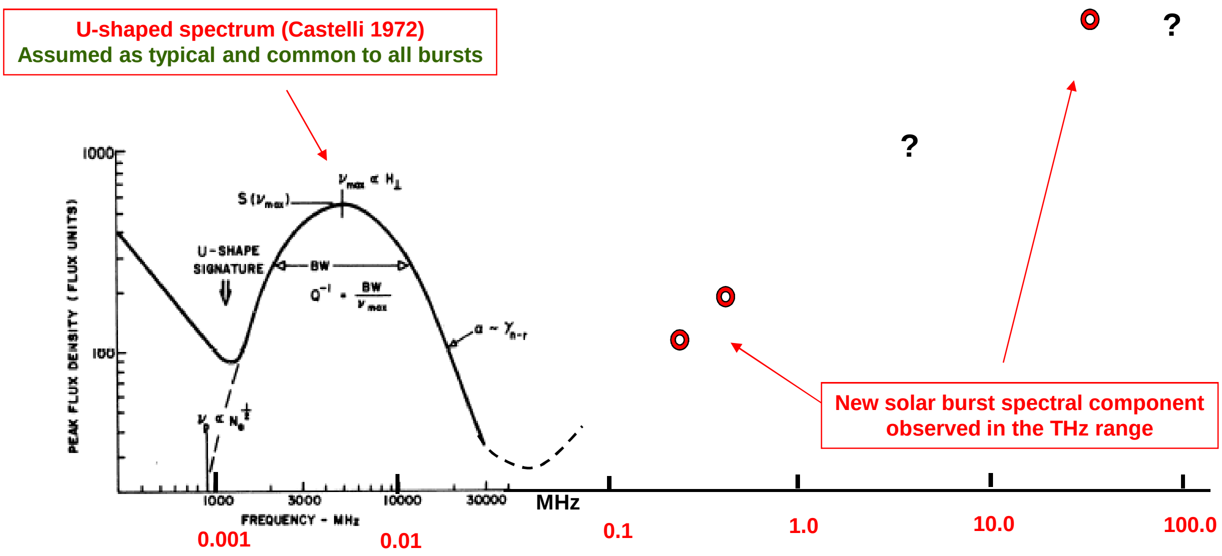
(Single beam slow scans)

250 GHz brightnings on AR, Clark & Park 1968, — ***Suggestive!***

250 GHz and 15 THz raster scans and tracking ARs, Hudson 1975 — ***Inconclusive***

2

INDICATION OF ANOTHER SOLAR BURST CONTINUUM SPECTRUM IN THz

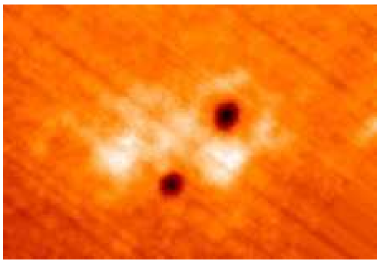


3

New Instrumentation to observe solar flares at sub-THz & 30 THz frequencies and circular polarization at mm-waves *(operated at El Leoncito site, Argentina Andes)*

45 and 90 GHz solar polarimeters POEMAS

Solar plages with 30 THz telescope



Sub-THz SST telescope

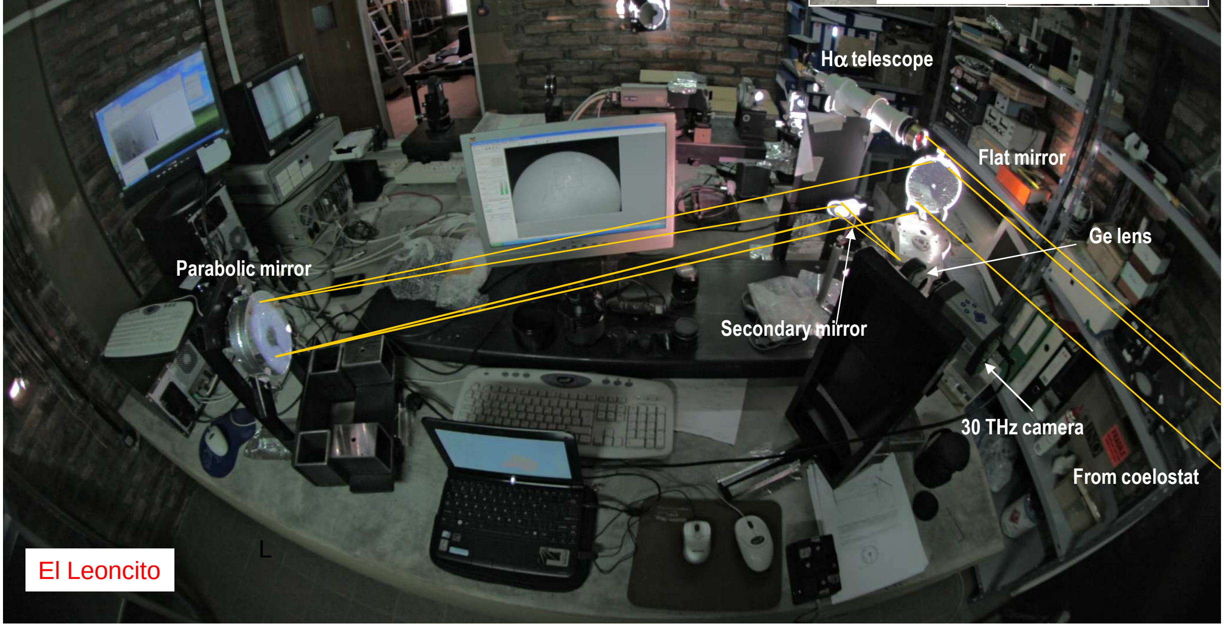
Multiple beams 0.2 THz (four radiometers) and 0.4 THz (two radiometers), 1.5 m Cassegrain reflector

4

30 THz

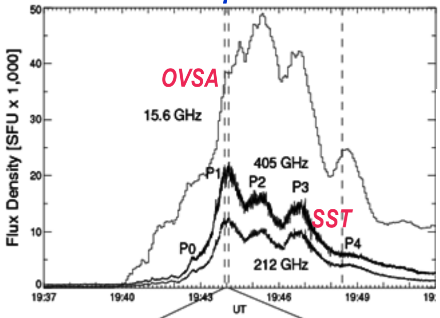

El Leoncito


Mackenzie, São Paulo

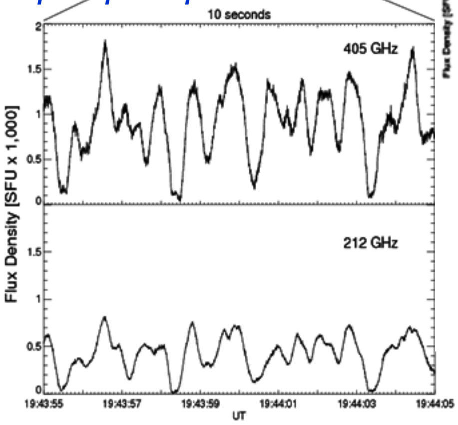

Hα telescope
Flat mirror
Ge lens
Parabolic mirror
Secondary mirror
30 THz camera
From coelostat
El Leoncito

New Terahertz Solar Burst Source – First Evidence
4 November 2003

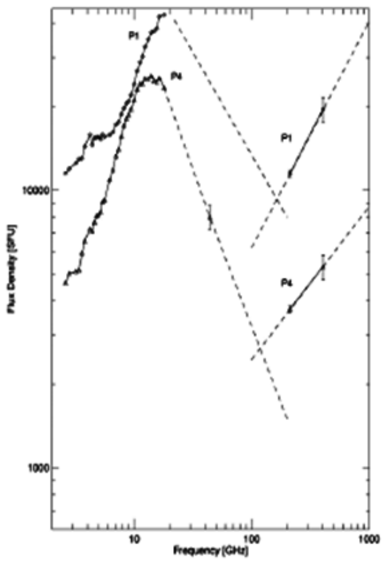
Time profiles



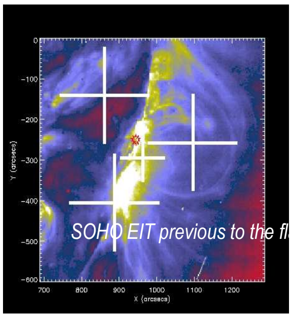
Rapid superimposed pulsations



Double spectra

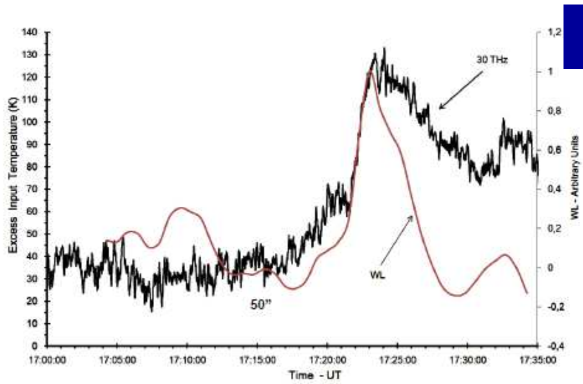


SST and X-rays(RHESSI) location

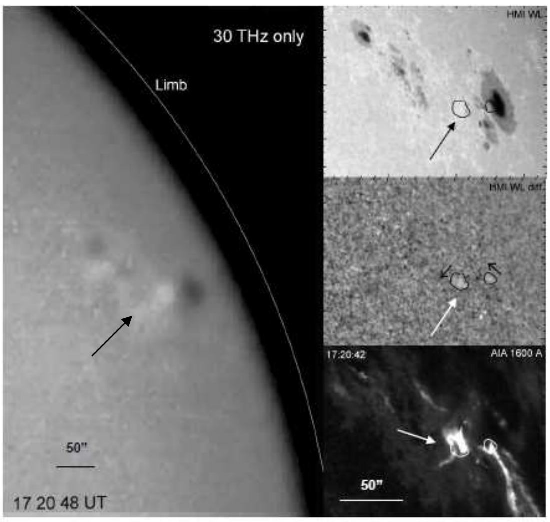


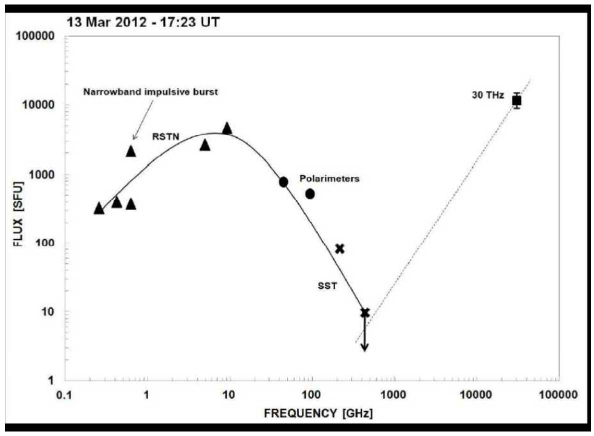
Kaufmann et al 2004

6



BRIGHT 30 THz IMPULSIVE BURST DETECTED WITH A M-CLASS SOLAR BURST (MARCH 13, 2012).

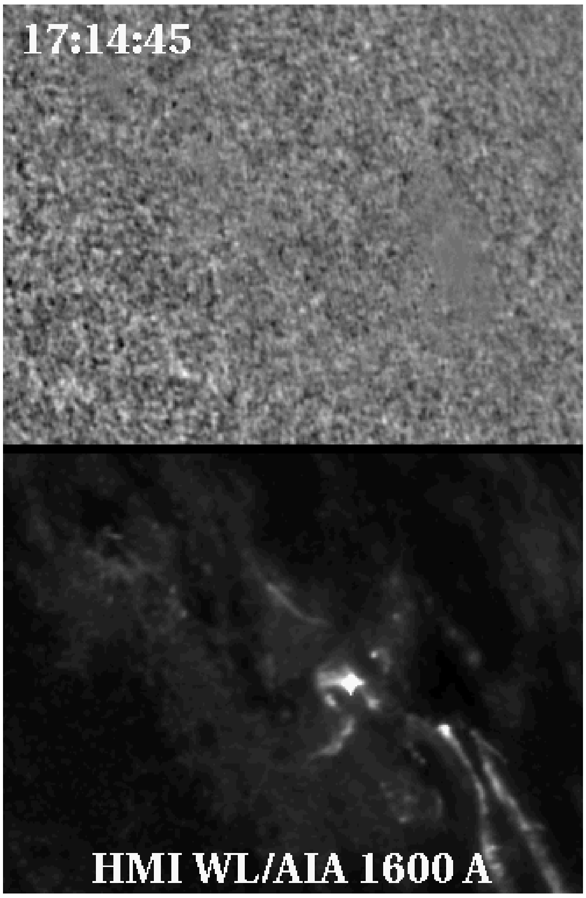




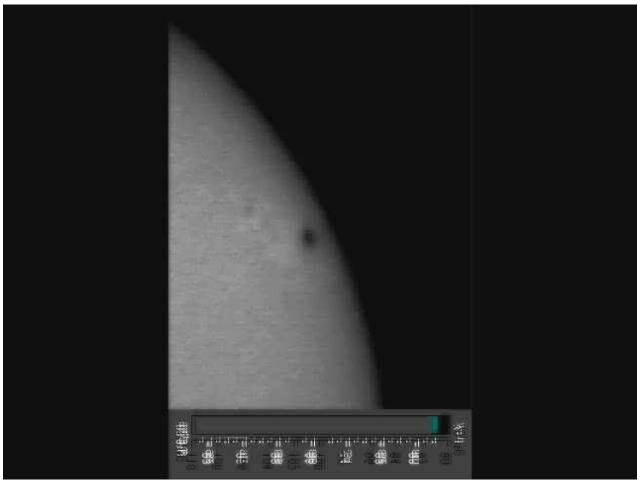
7

Kaufmann et al. et al., 2013

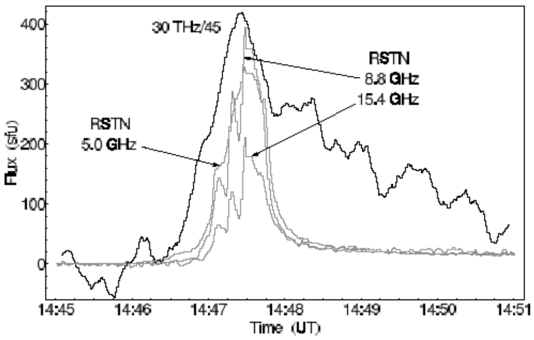
White Light

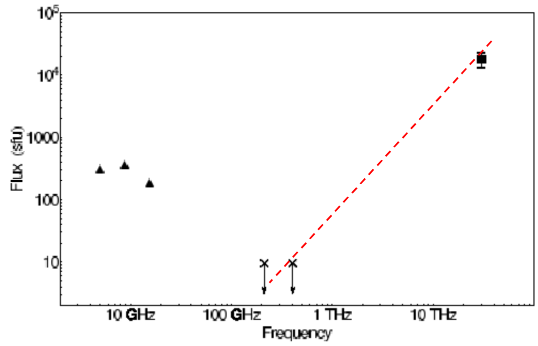


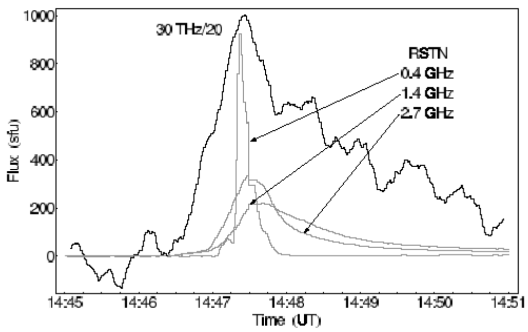
30 THz

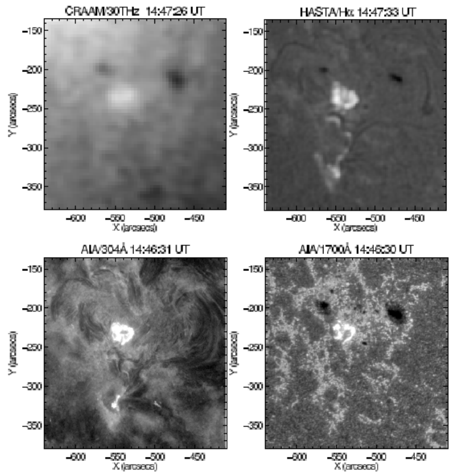


30 THz IMPULSIVE BURST DETECTED AT SÃO PAULO WITH A M-CLASS SOLAR BURST (AUGUST 1st, 2014).









Miteva et al., 2015

OTHER RECENT PRELIMINARY RESULTS

October 27, 2014, 1420 UT GOES X2 burst
30000 SFU at 30 THz (São Paulo); 200 SFU at 0.4 THz; 20 SFU at 0.2 THz (SST)

30 and 60 THz brightnings obtained by NSO with McMath-Pierce Solar Telescope, Kitt Peak, AZ, for a C7 class burst

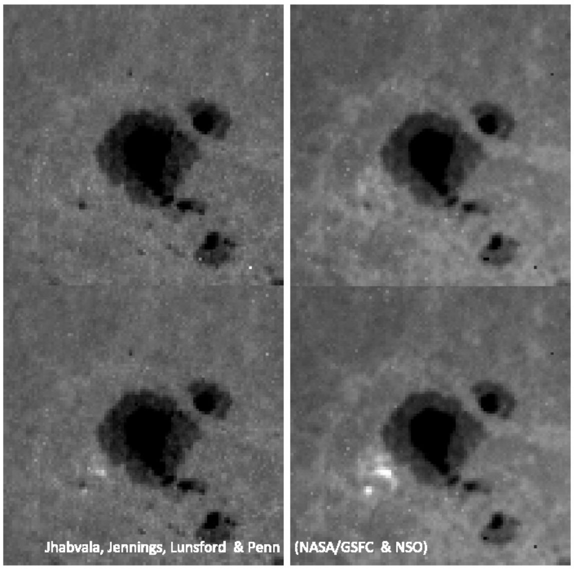
Courtesy from Matt Penn, NSO

20140924
17:45UT
C7.0

60 THz | 30 THz

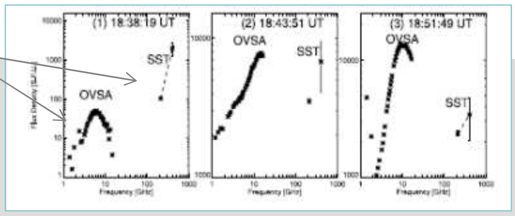
t0

t0 +20sec



THz BURST SOURCE PARAMETERS DIFFICULT TO RECONCILE TO SUGGESTED MODELS

Double spectrum

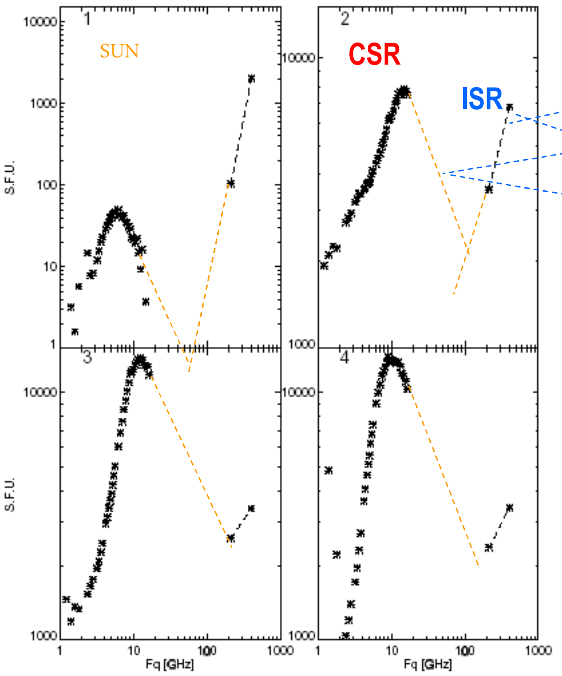


Several suggested tentative interpretations:
<u>All addresses to the high sub-THz component</u>

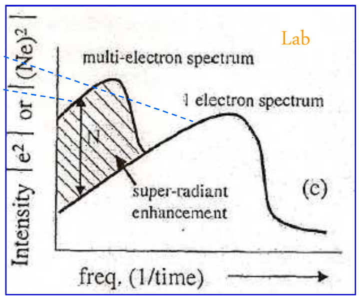
- **SYNCHROTRON OF UR ELECTRONS (Stein & Ney 1963; Schklovsky 1964)**
- **THERMAL (as for example Ohki & Hudson 1975)**
- **SYNCHROTRON, RAZIN SUPPRESSION, GEOMETRY (Silva et al. 2007, Melnikov 2011)**
- **SYNCHROTRON BY POSITRONS (Silva *et al.* 2007, Trottet *et al.* 2008)**
- **POSITRONS BY PROTON-PROTON DRELL-YAN PROCESS (Szpiegel, Durães & Steffens 2007)**
- **LANGMUIR WAVES BY ELECTRON AND PROTON BEAMS (Sakai *et al.* 2006, Sakai and Nagasushi 2007)**
- **INVERSE COMPTON ON SYNCHROTRON PHOTON FIELD (Kaufmann *et al*. 1985)**
- **INVERSE COMPTON ON TURBULENT PLASMA WAVES (Fleishman and Kontar 2010)**
- **CERENKOV RADIATION (Fleishman and Kontar 2010)**
- **DENSE PLASMA PULSATIONS (Stepanov *et al.* 2012, Zaitsev *et al.* 2014)**

Simultaneous double-spectral (microwaves & THz) component difficult to explain

A SIMPLER POSSIBILITY
Same physics as in laboratory
BUNCHING OF ACCELERATED UR ELECTRON BEAMS



FLUX ∝ P_o [N*(incoherent)* + f N^2*(coherent)*]



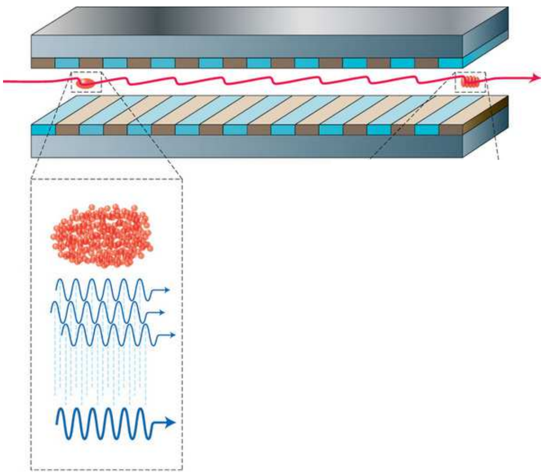
THE MECHANISM IS SO EFFICIENT THAT JUST A SMALL FRACTION OF ELECTRONS BUNCHED WITHIN SOLAR ACCELERATED BEAM (i.e. form factor f <<1) ARE ENOUGH TO ACCOUNT FOR THE BROADBAND COHERENT SYNCHROTRON EMISSION AT MICROWAVES

A SIMPLER POSSIBILITY

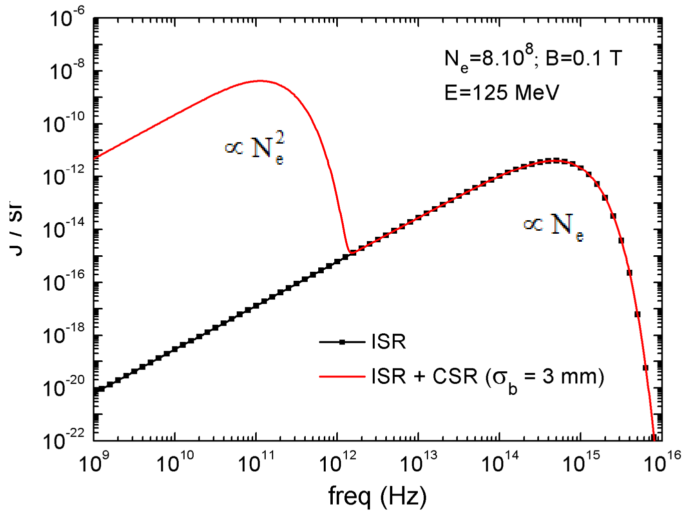
Same physics as in laboratory

BUNCHING OF ACCELERATED UR ELECTRON BEAMS

See Szpiegel et al., this meeting; Klopf et al. 2014



$\lambda < \sigma_b$



- $\lambda < \sigma_b$ **: the emission from the electrons is incoherent and the resulting radiation exhibits the well-known incoherent synchrotron radiation (ISR) spectrum emitted by charged particles accelerated to relativistic energies in dipole magnetic fields.**

- $\lambda \geq \sigma_b$ **: the near field of the radiation emitted from each accelerated electron overlaps the entire microbunch, resulting in a coherent interaction which produces intense broadband coherent synchrotron radiation (CSR).**

Observations at the THz range of frequencies provide a new window for flare studies

SOME OPEN QUESTIONS

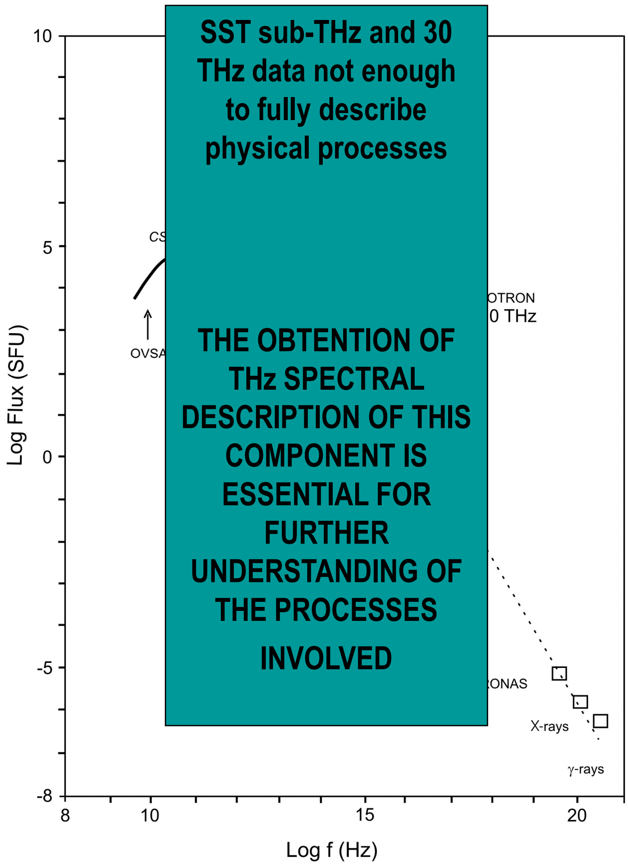
- Are the 30 THz impulsive component, the WL and sub-THz part of the same emission process?

- Where is the 30 THz impulsive emission component located?

- Where is located the accelerator

- Fluxes time-histories at microwaves, THz range, hard x-rays

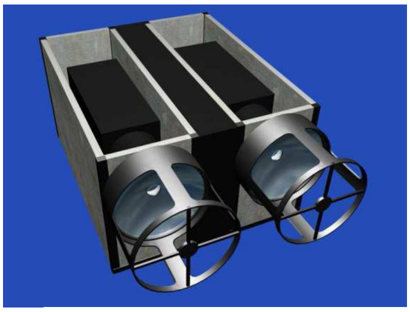
- Relative importances of ISR and bremssstrahlung to produce hard x- and gamma rays

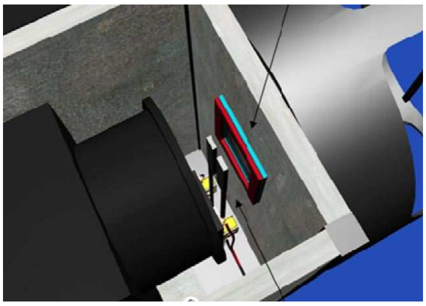


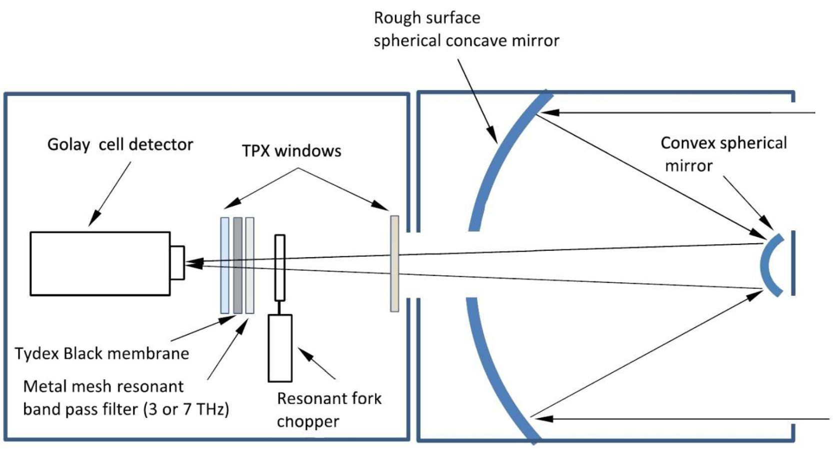
SST sub-THz and 30 THz data not enough to fully describe physical processes

THE OBTENTION OF THz SPECTRAL DESCRIPTION OF THIS COMPONENT IS ESSENTIAL FOR FURTHER UNDERSTANDING OF THE PROCESSES INVOLVED

NEW PROJECT: Flare THz observations from space: SOLAR-T design concept (3 and 7 THz)

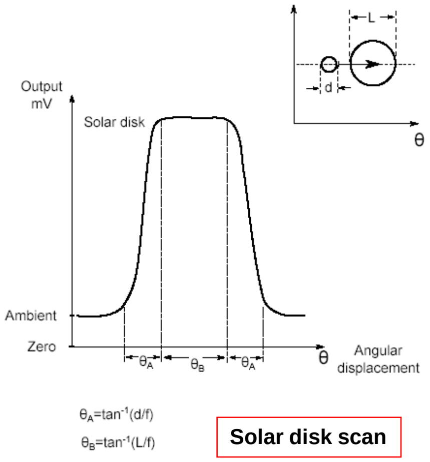


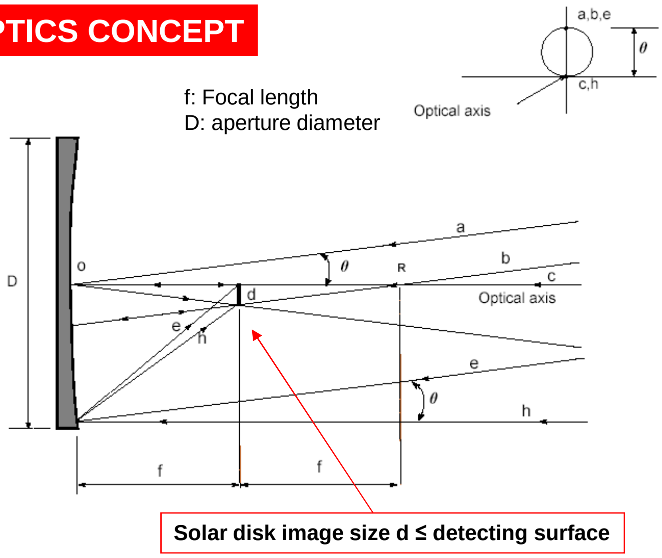




15

THE OPTICS CONCEPT





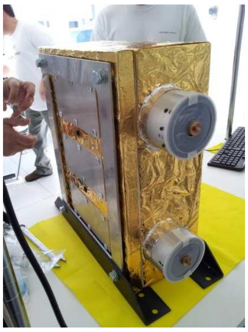
1) d = f tan θ fixed short focal length f

2) $G(\phi,\theta) = 4\pi A_e(\phi,\theta)/\lambda^2$

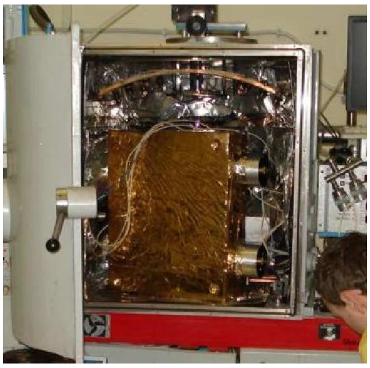
3) Flux densities $\Delta S \approx 2\ k\ \Delta T/A_e$

16

SOLAR-T 3 AND 7 THz PHOTOMETERS FLIGHT MODEL FABRICATION (TYDEX, ST. PETERSBURG)

76 mm Cassegrain telescopes with rough surface primary mirrors (build by Marcon, OSBL)
Metal mesh band-pass filters
Build by CCS/Unicamp

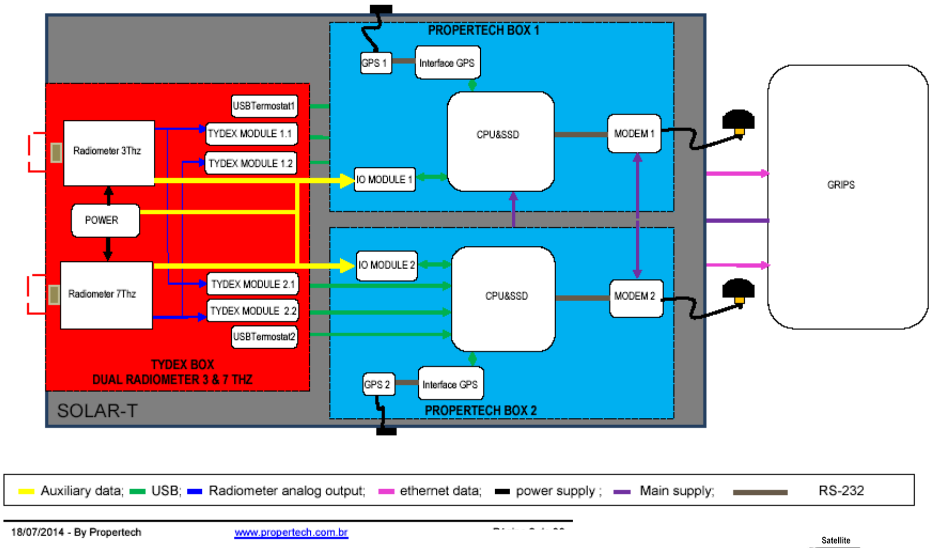


Complete SOLAR-T assembly was submitted to operative tests at low pressure (1000 HPa) and low temperature -25 C

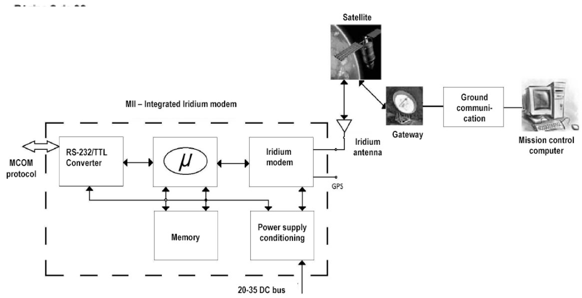
Completed and tested May 2012

17

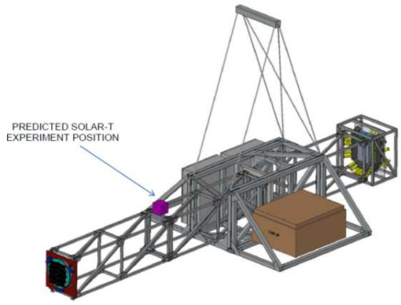
SOLAR-T DATA ACQUISITION BLOCK DIAGRAM (PROPERTECH)



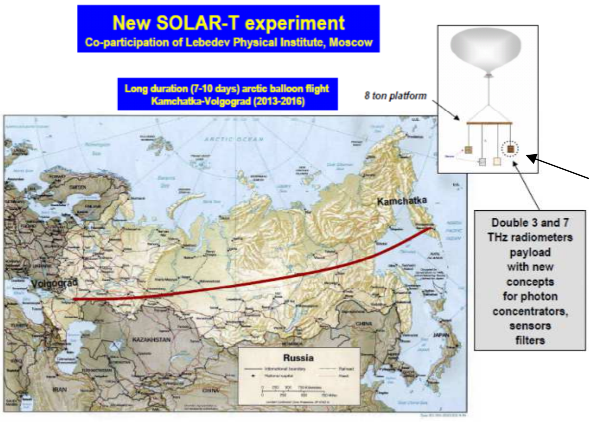
IRIDIUM SHORT-BURST-DATA SERVICES (NEURON)



TWO LONG DURATION STRATOSPHERIC BALLOON FLIGHTS



On GRIPS mission
SSL, U California, Berkeley
Thermo-vacuum tests Feb 2015
Long duration flight in Antarctica
(30 days Summer 2015-2016)



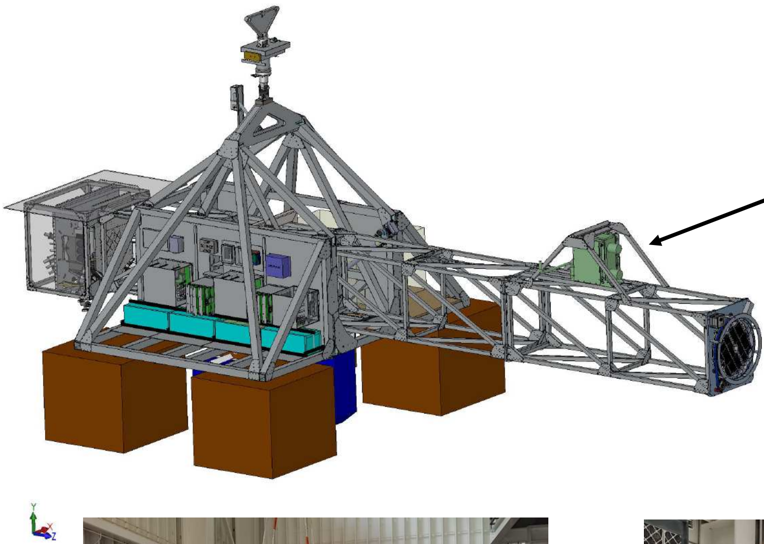
Mackenzie EE-CRAAM, UNICAMP-CCS, INPE, CTI, INATEL, CONICET-CASLEO (Argentina)

Long duration balloon flight (7-10 days)
Kamchatka-Volga
Lebedev Physical Institute, Moscow, Russia
University of California Santa Barbara
(2016-2017)

ECG, UCSB Gondola

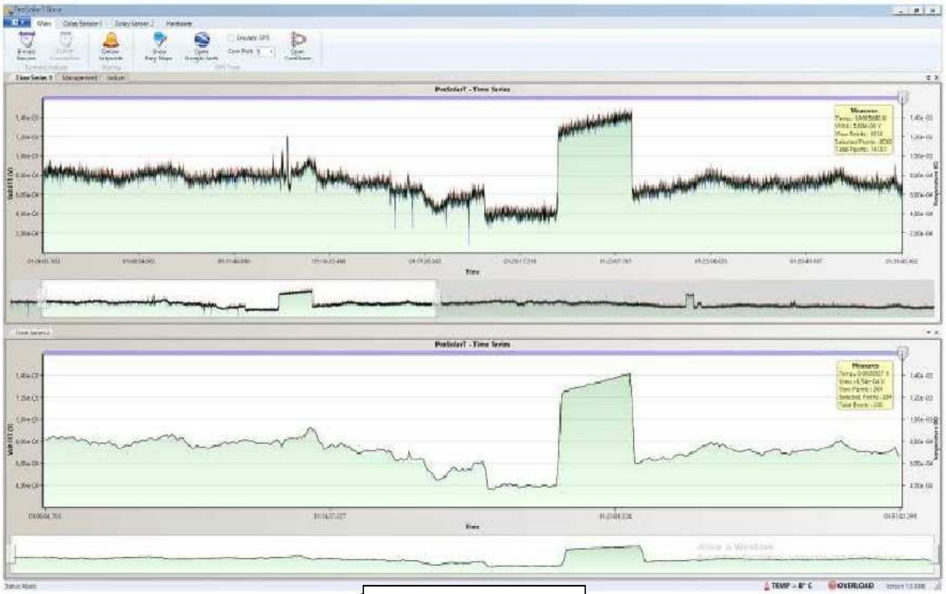
9

SOLAR-T TESTS ON GRIPS, SSL, U. CALIFORNIA, BERKELEY, JULY 2014



SOLAR-T TESTS ON GRIPS, SSL, U. CALIFORNIA, BERKELEY, JULY 2014

Data acquisition, conditioning, transmission to Iridium satellites, reception by two redundant boxes



On board
(data transmitted from SOLAR-T at SSL to Iridium SDBS for tests)

On ground station
(data received from SOLAR-T at SSL via Iridium SDBS for tests) No data lost

40 minutes example

7 THz photometer
(Similar results for 3 THz photometer)

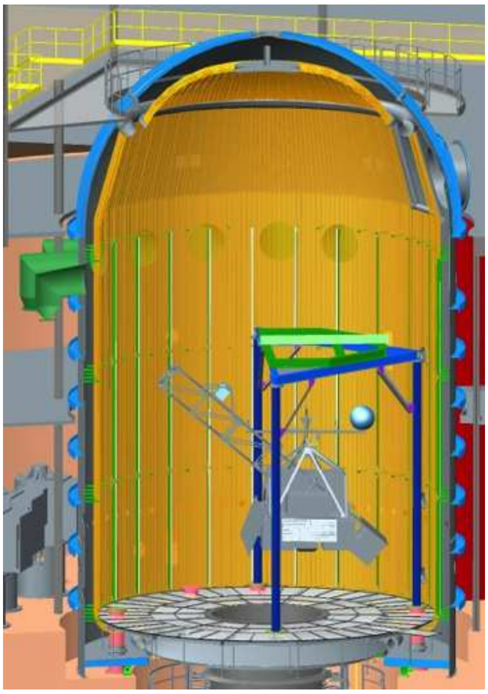
21

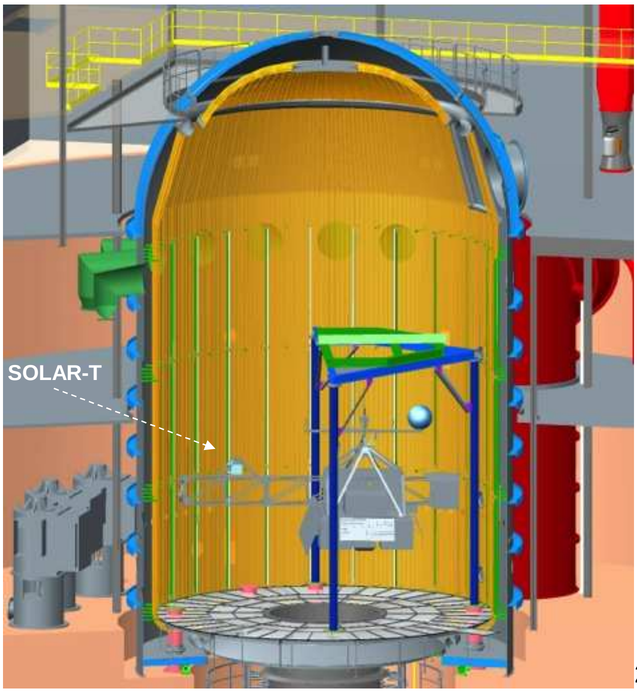
FOLLOWING PHASES 2015-2016

NASA Glenn at Plum Brook Station Sandusky Ohio

GRIPS Telescope & SOLAR-T Test Installation

Thermo-vacuum tests – planned for 2-13 March 2015





2

22

FOLLOWING PHASES 2015-2016

Final integration of SOLAR-T on GRIPS at NASA Columbia Scientific Balloon Facility (CSBF) Palestine, TX, before shipment to Antarctica: August 2015

SOLAR-T on GRIPS stratosphere balloon launch by NASA Columbia Scientific Balloon Facility for one-month flight over Antarctica – December 2015-January 2016

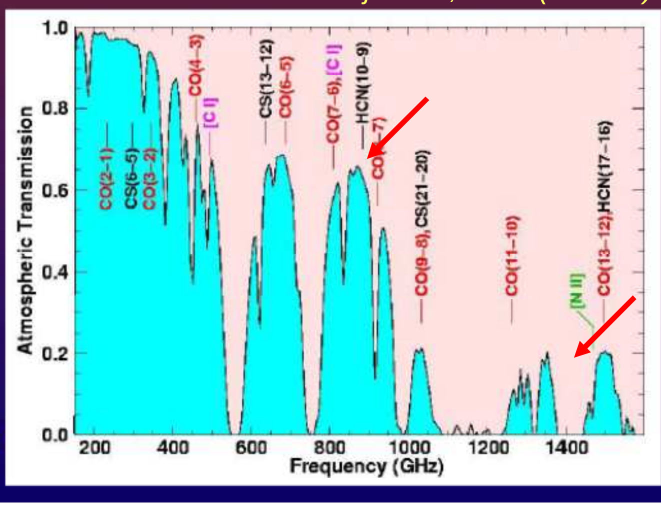
23

NEW PROJECT: High Altitude THz Solar telescope: HATS
(currently being fabricated at Mackenzie, OSBL-Marcon, CCS-Unicamp and Propertech)

Atmospheric Transmission Spectra
The Best Data

- ~ 10:30 AM, June 17th, 1998.
  - 220 GHz ~ 98 % (τ~0.016)
  - 650 & 850 GHz submm windows ~ 67 % (τ~0.40)
  - THz windows ~ 20 % (τ~1.6)
  - PWV ~ 0.284 mm

Chajnantor, Chile (5000 m)

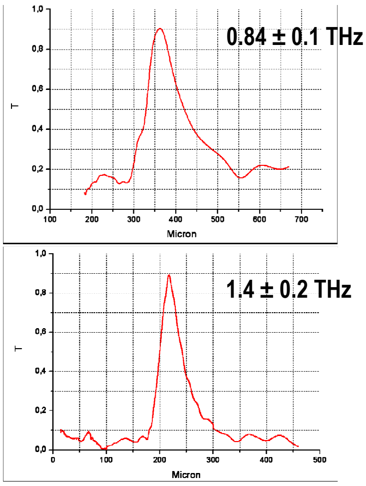


24

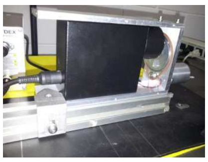
Matsushita el al.1999

NEW PROJECT: High Altitude THz Solar telescope: HATS
Same optical concept used for SOLAR-T

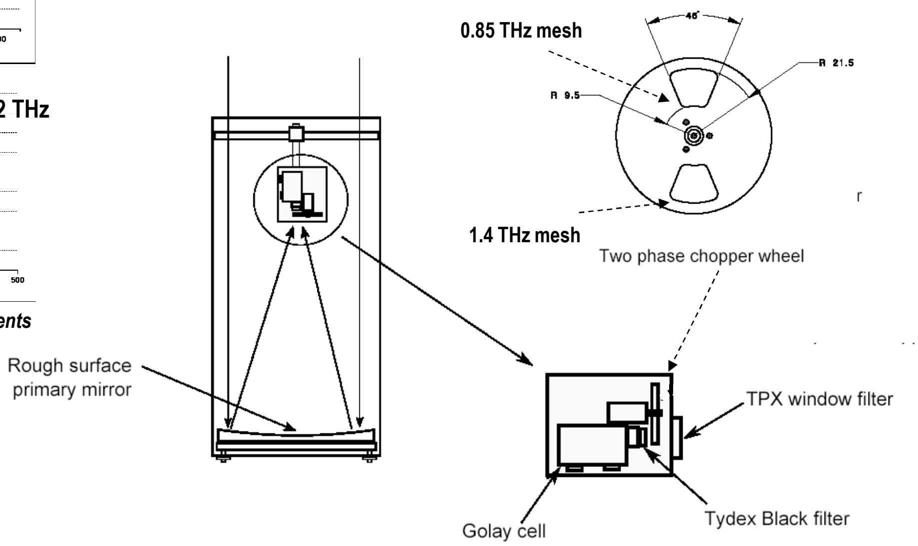
Band-pass CCS built filters



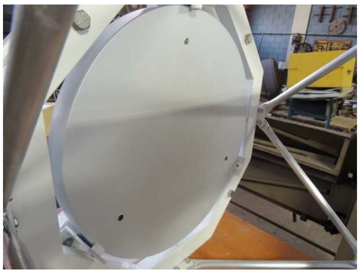
Tydex FTR Band-pass measurements



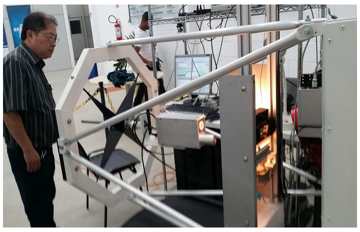
Ground-based two-frequency photometer

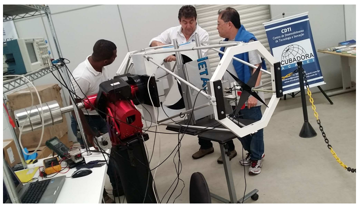


HATS 46 cm THz telescope



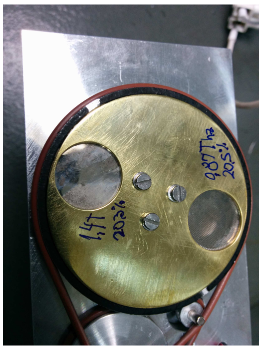
Rough surface 46 cm mirror





Performance tests

Hutech Hinode sun-tracker



Chopper wheel with
Two band-pass filters

Paramount robotic mount

HATS expected performance

Rough mirror reflection	0.95
Two 2mm TPX windows	0.85x0.85
Low-pass membranes	0.4
Band-pass filter	0.9
Telescope aperture blockage	0.85
Net transmission	0.21

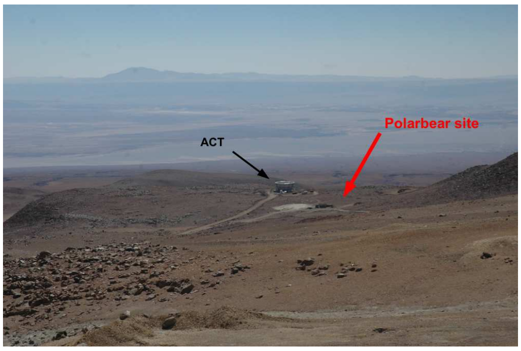
HATS physical aperture 0.17 m^2
HATS effective aperture area: 0.04 m^2

Atmosphere transmission a site with PWV < 1 mm at zenith: 0.5 at 0.85 THz and 0.15 at 1.4 THz for more than 100 days/year (i.e. optical depth $\tau \approx 0.7$ and 1.9 respectively)

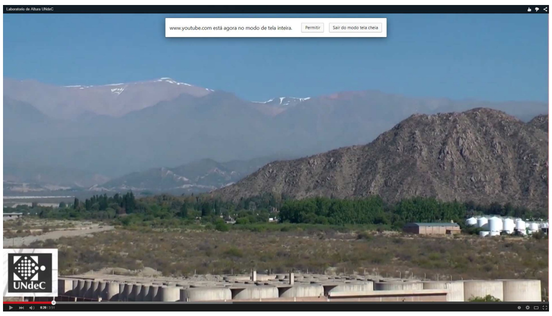
3 σ flux detection at 45º elevation

40 SFU at 0.85 THz
140 SFU at 1.4 THz
1 SFU = 10^{-22} W m^{-2} Hz^{-1}

27

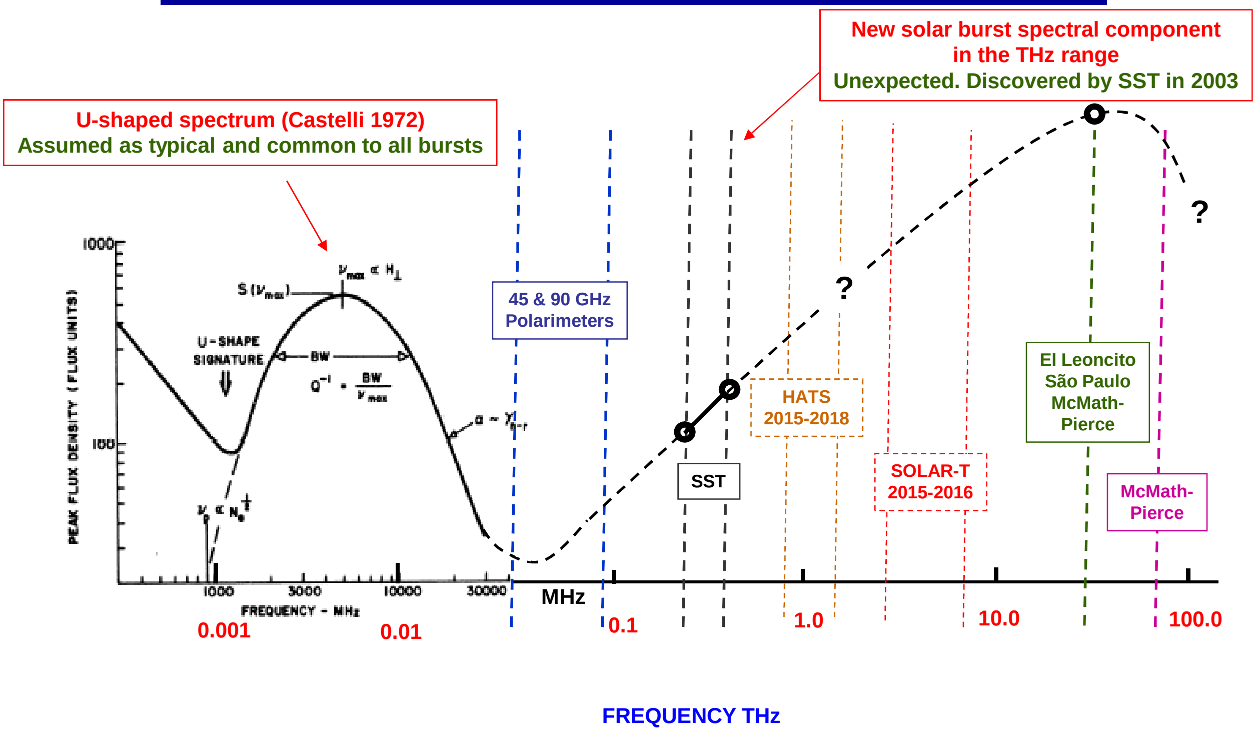


Parque Astronomico de Atacama, CONICYT, Chile, 5200m altitude



Laboratorio de Altura, Lampallado, Sierra Famatina, Argentina, 5100m altitude

NEW OBSERVATIONS OF SOLAR BURST CONTINUUM SPECTRUM



Thank you!

29

March 16 - 18, 2015, Cambridge, Massachusetts, U.S.A.

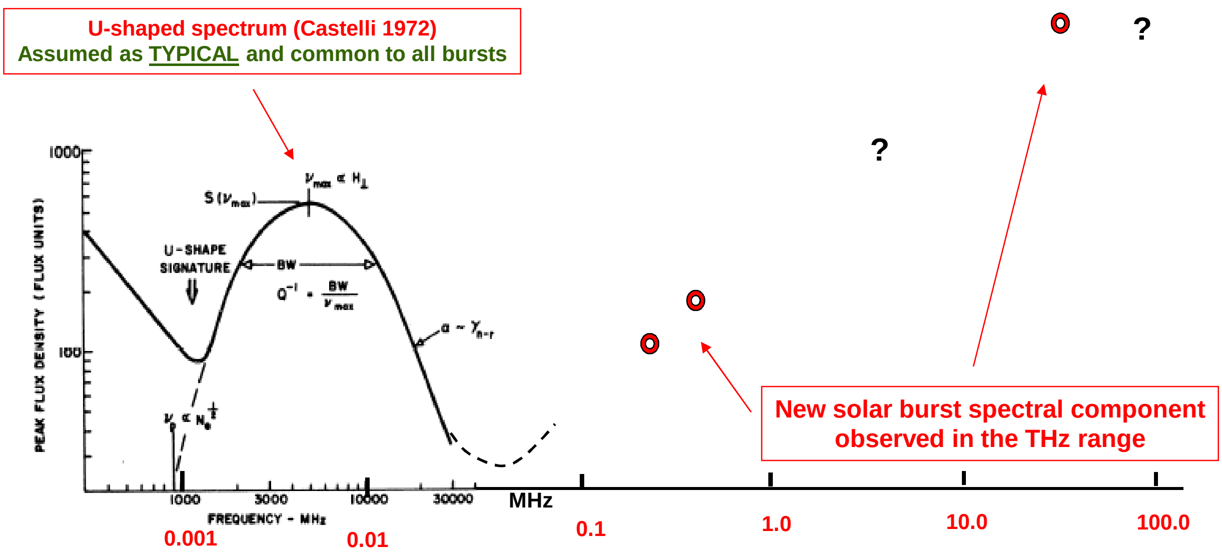
SPACE AND GROUND-BASED NEW TOOLS FOR THz SOLAR FLARE OBSERVATIONS

Pierre Kaufmann
Universidade Presbiteriana Mackenzie
São Paulo, SP. Brazil
Universidade Estadual de Campinas
Campinas, SP, Brazil

Funding agencies:

THE SCIENTIFIC PROBLEM: SOLAR BURSTS SPECTRA AT HIGHER FREQUENCIES

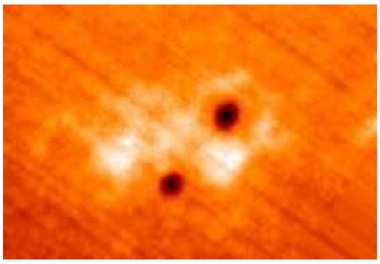
RECENT EVIDENCES FOR SOLAR BURST CONTINUUM SPECTRUM IN THz



Instrumentation to observe solar flares at sub-THz & 30 THz frequencies and circular polarization at mm-waves *(operated at El Leoncito site, Argentina Andes)*

45 and 90 GHz solar polarimeters POEMAS

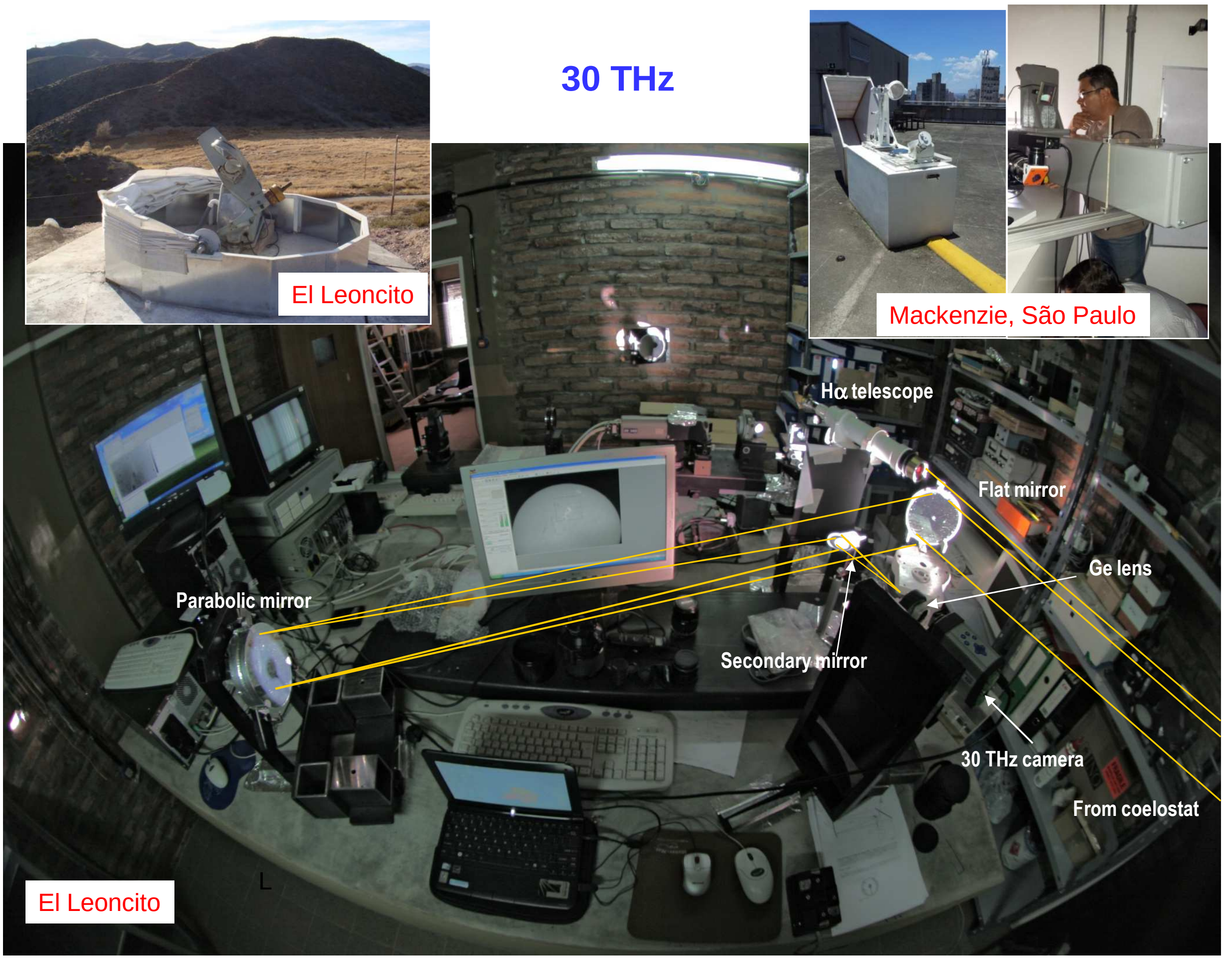
Solar plages with 30 THz telescope



Sub-THz SST telescope

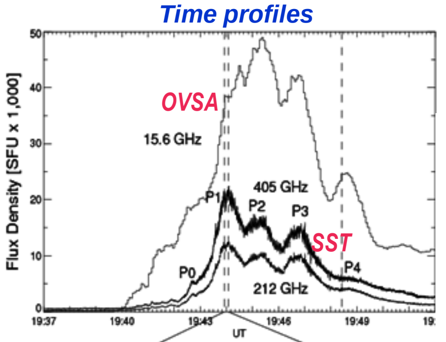
Multiple beams 0.2 THz (four radiometers) and 0.4 THz (two radiometers), 1.5 m Cassegrain reflector

30 THz

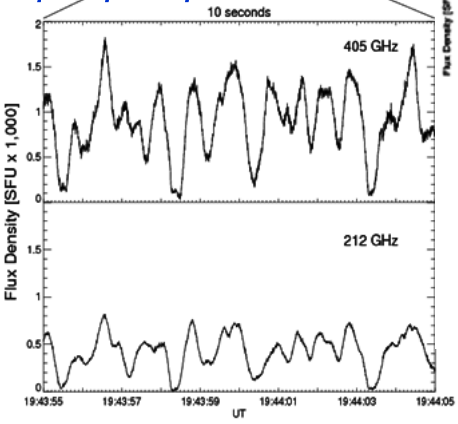

El Leoncito
Mackenzie, São Paulo
Hα telescope
Flat mirror
Ge lens
Parabolic mirror
Secondary mirror
30 THz camera
From coelostat
El Leoncito

New Terahertz Solar Burst Source – First Evidence
4 November 2003

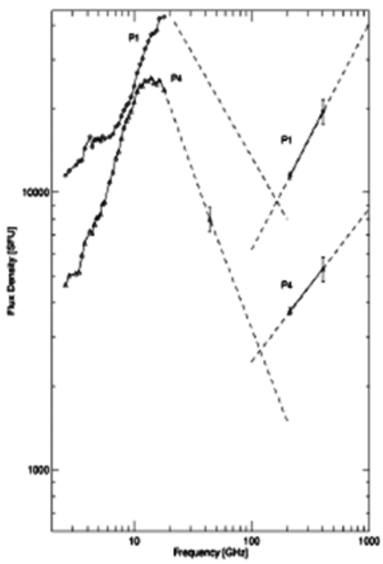
Time profiles



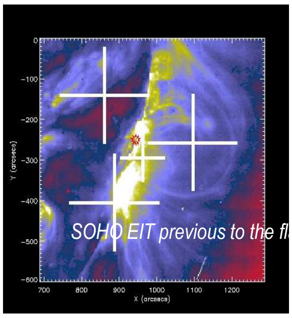
Rapid superimposed pulsations



Double spectra

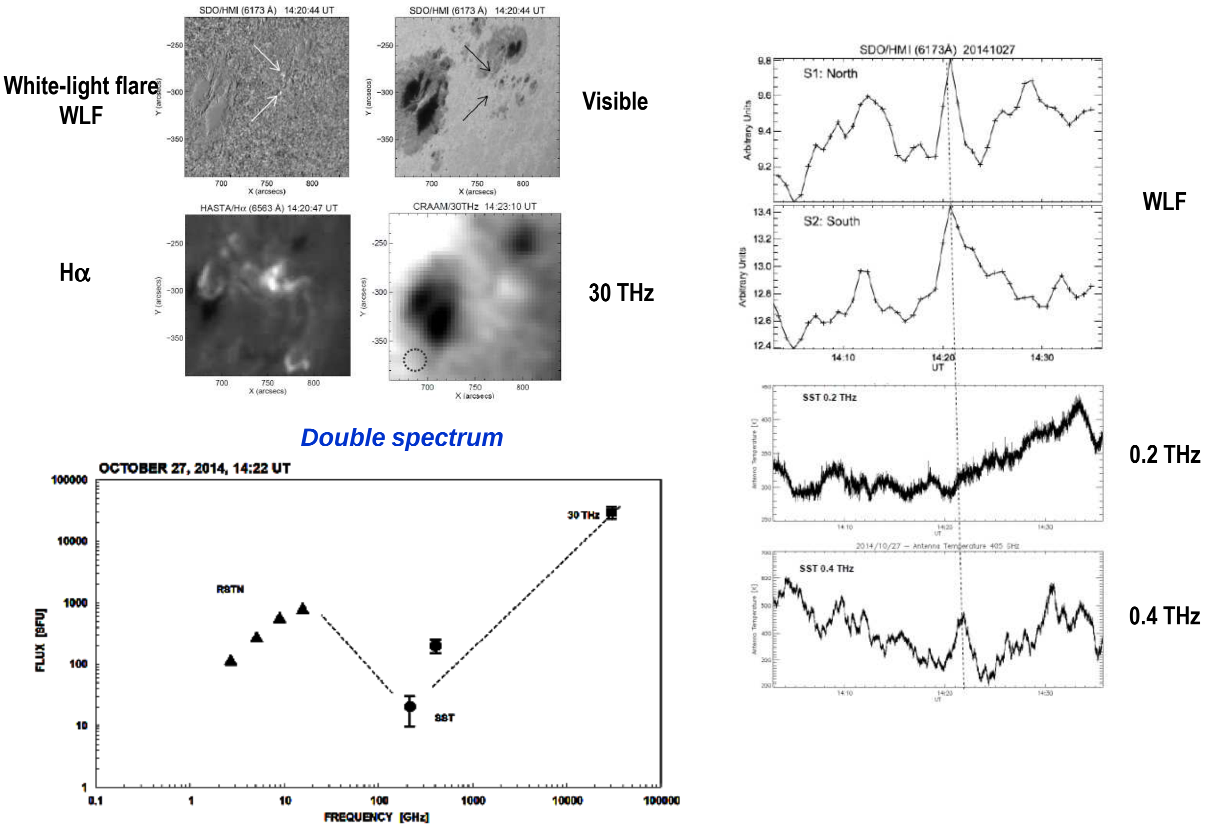


SST and X-rays(RHESSI) location



Kaufmann et al 2004

30 THz IMPULSIVE BURST DETECTED AT SÃO PAULO WITH A M-CLASS SOLAR BURST (October 27, 2014).

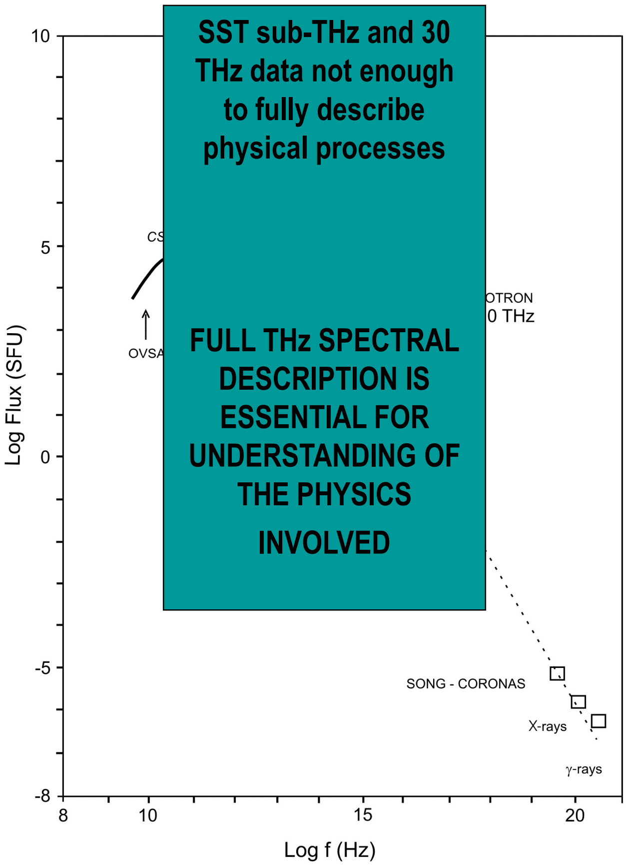


Observations at the THz range of frequencies provide a new window for flare studies

EVIDENCE OF RADIATION BY VERY HIGH ENERGY ELECTRONS IN FLARES

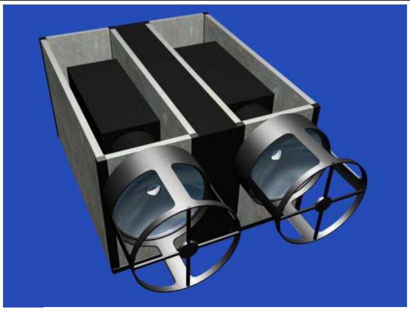
BURST SOURCE PARAMETERS DIFFICULT TO RECONCILE TO SEVERAL SUGGESTED MODELS

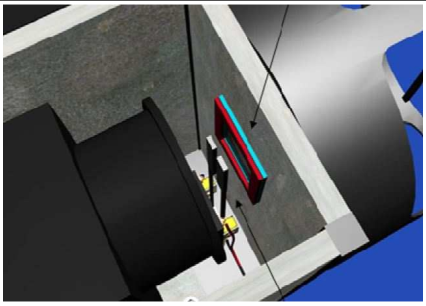
SIMULTANEOUS DOUBLE-SPECTRAL (MICROWAVES & THz) COMPONENT DIFFFICULT TO EXPLAIN

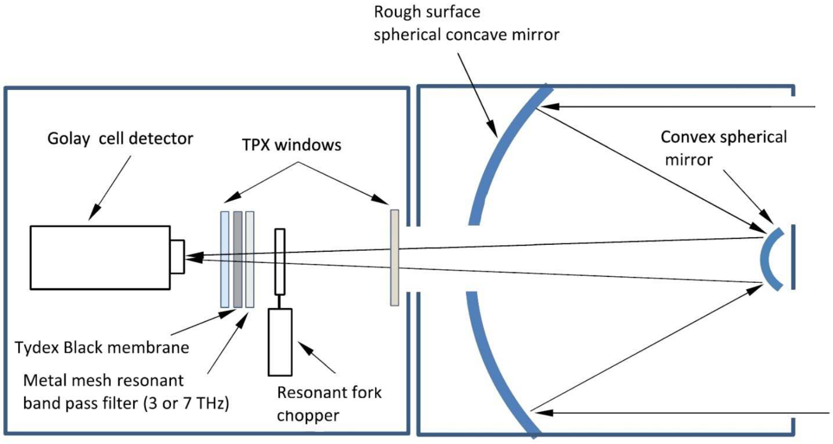


SOLAR-T : Flare THz observations from space: design concept (3 and 7 THz)

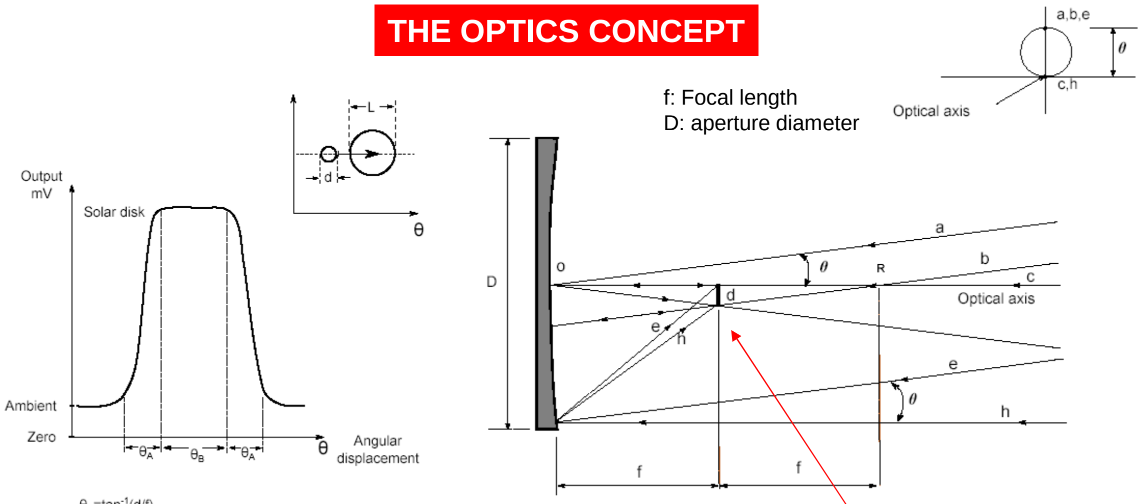
CONCEIVED AND CONSTRUCTED TO FLY ON STRATOSPHERIC BALLOON MISSIONS







THE OPTICS CONCEPT



Solar disk scan

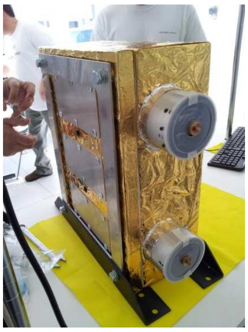
Solar disk image size d ≤ detecting surface

1) $d = f \tan\theta$ fixed short focal length f

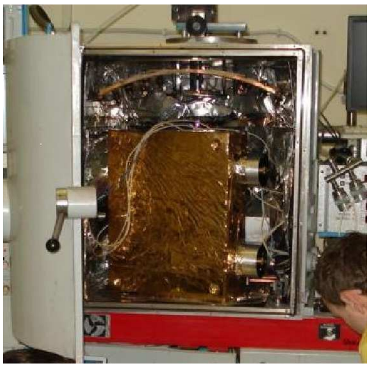
2) $G(\phi,\theta) = 4\pi A_e(\phi,\theta)/\lambda^2$

3) Flux densities $\Delta S \approx 2 k \Delta T/A_e$

SOLAR-T 3 AND 7 THz PHOTOMETERS FLIGHT MODEL FABRICATION (TYDEX, ST. PETERSBURG)



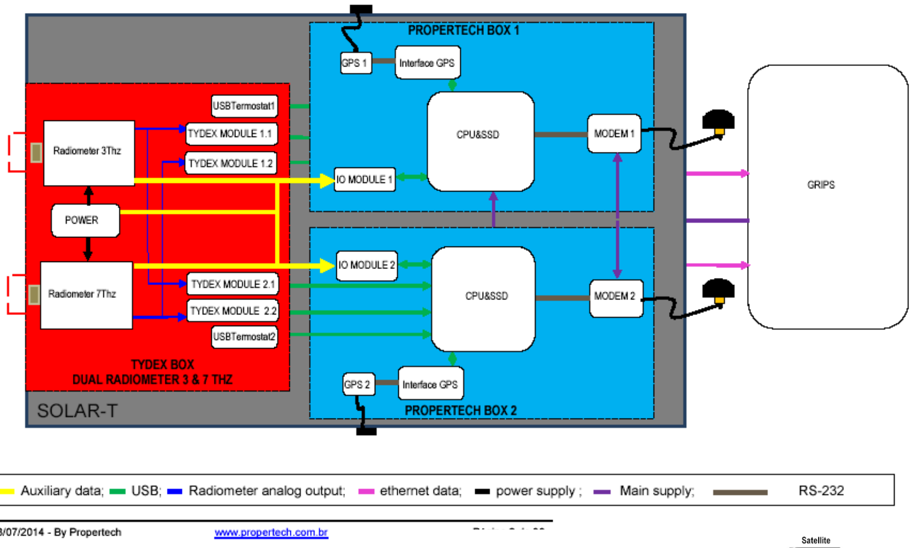
76 mm Cassegrain telescopes with rough surface primary mirrors (build by Marcon, OSBL)
Metal mesh band-pass filters
Build by CCS/Unicamp



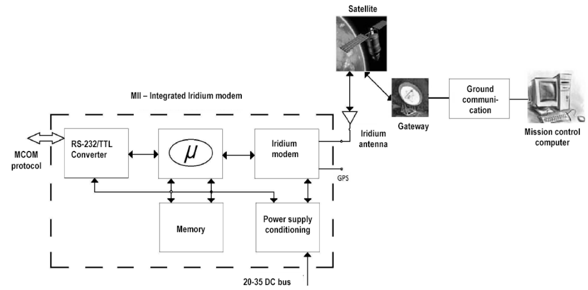
Complete SOLAR-T assembly was submitted to operative tests at low pressure (1000 HPa) and low temperature -25 C

Completed and tested May 2012

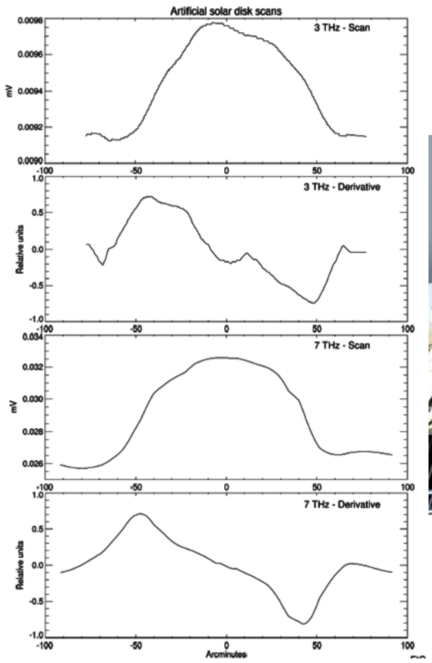
SOLAR-T DATA ACQUISITION BLOCK DIAGRAM (PROPERTECH, JACAREÍ, BR)

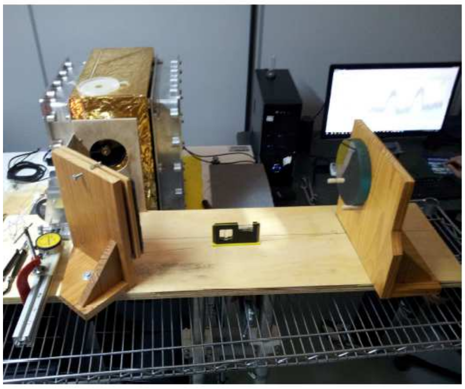


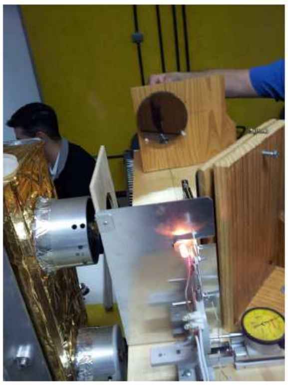
IRIDIUM SHORT-BURST-DATA SERVICES (NEURON, S.J. CAMPOS, BR)



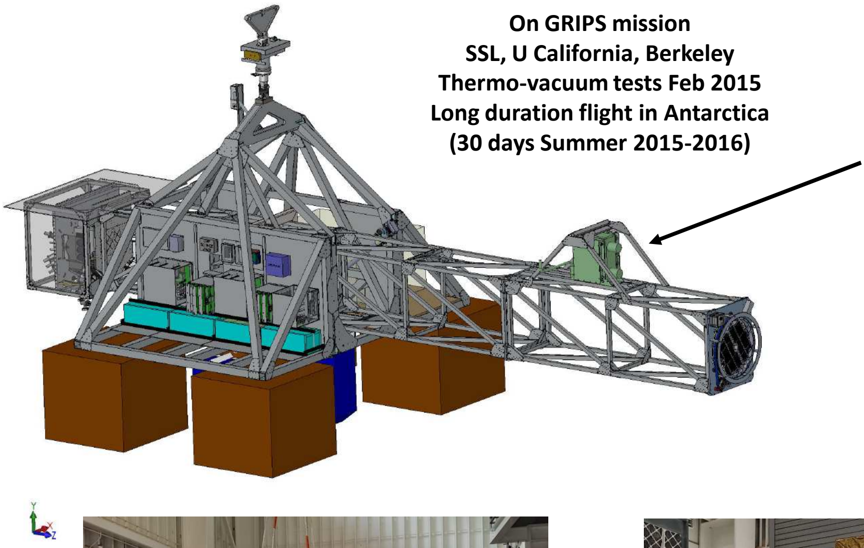
SOLAR-T calibrations using na “artificial Sun” blackbody source







SOLAR-T TESTS ON GRIPS, SSL, U. CALIFORNIA, BERKELEY, JULY 2014



On GRIPS mission
SSL, U California, Berkeley
Thermo-vacuum tests Feb 2015
Long duration flight in Antarctica
(30 days Summer 2015-2016)

SOLAR-T TESTS ON GRIPS, SSL, U. CALIFORNIA, BERKELEY, JULY 2014

Data acquisition, conditioning, transmission to Iridium satellites, reception by two redundant boxes

On board
(data transmitted from SOLAR-T at SSL to Iridium SDBS for tests)

On ground station
(data received from SOLAR-T at SSL via Iridium SDBS for tests) No data lost

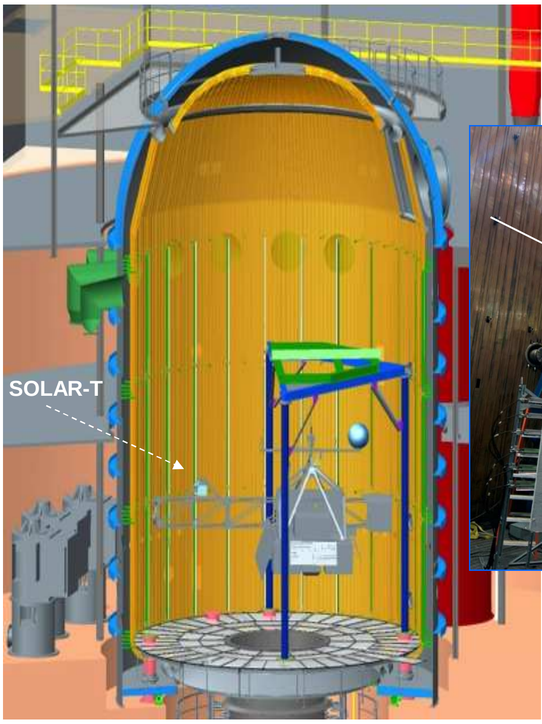
40 minutes example

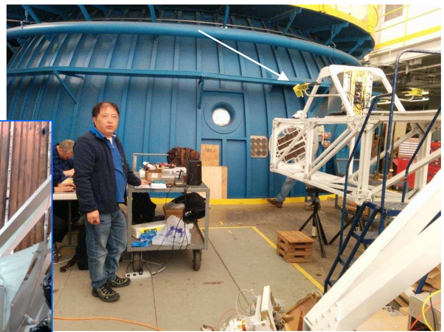
7 THz photometer
(Similar results for 3 THz photometer)

CURRENT PHASE 2015-2016

GRIPS Telescope & SOLAR-T Test Installation

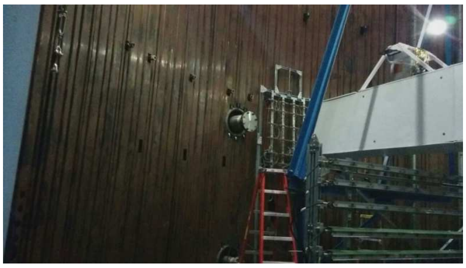
Thermo-vacuum tests – 5-20 March 2015

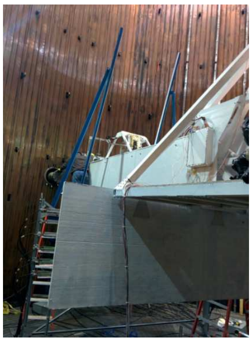


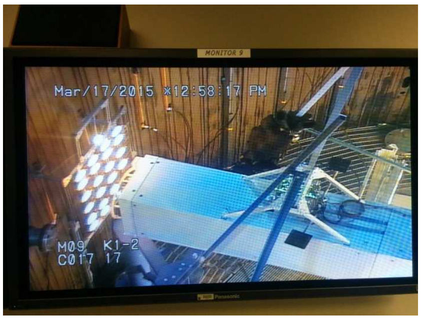


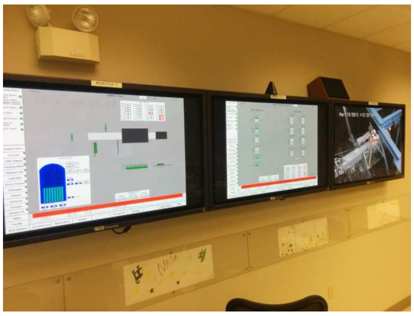
15

SOLAR-T AT TOP OF GRIPS BOOM INSIDE THERMO-VACUUM CHAMBER









SOLAR-T PERFORMANCE TESTS AT 3 THz (TOP) and 7 THz (BOTTOM)

FOLLOWING PHASE 2015-2016

1) Final integration of SOLAR-T on GRIPS at NASA Columbia Scientific Balloon Facility (CSBF) Palestine, TX, before shipment to Antarctica: August 2015

2) SOLAR-T on GRIPS stratosphere balloon launch by NASA Columbia Scientific Balloon Facility for one-month flight over Antarctica – December 2015-January 2016

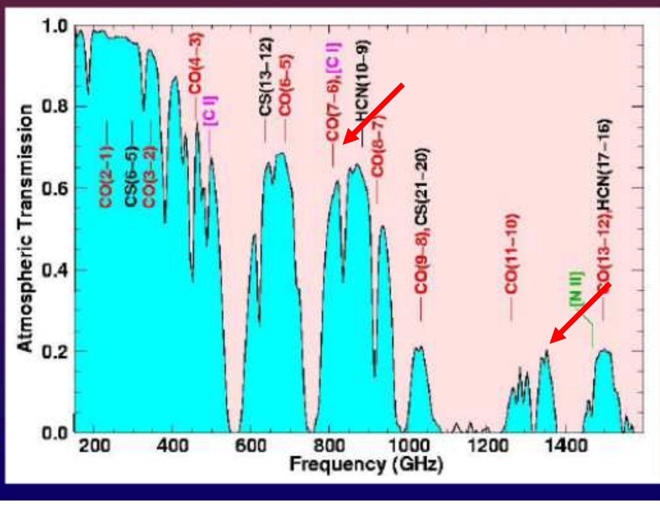
Ground-based HATS: "High Altitude THz Solar telescope"
(Finalized Mackenzie, OSBL-Marcon, CCS-Unicamp and Propertech)

Atmospheric Transmission Spectra

Sub THz and THz windows

Chajnantor, Chile (5000 m)

- 220 GHz ~ 98 % (τ~0.016)
- 650 & 850 GHz submm windows ~ 67 % (τ~0.40)
- THz windows ~ 20 % (τ~1.6)
- PWV ~ 0.284 mm

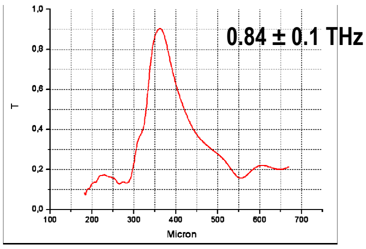


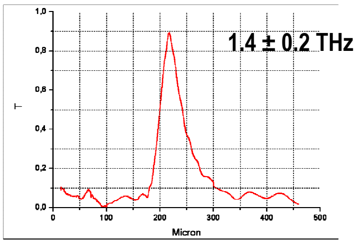
Matsushita el al.1999

NEW PROJECT: High Altitude THz Solar telescope: HATS

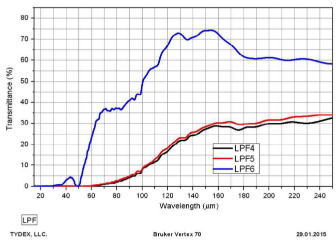
Same optical concept used for SOLAR-T

Band-pass CCS built filters



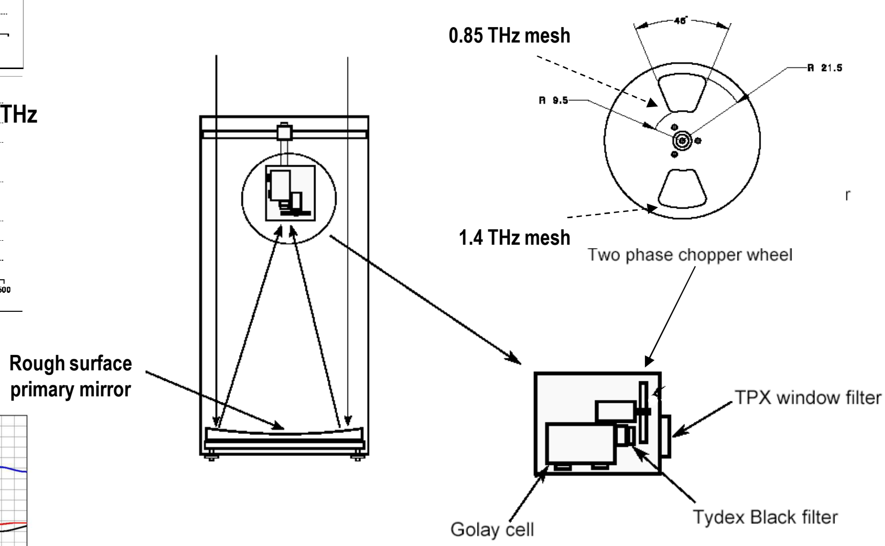


Low-pass Tydex filters

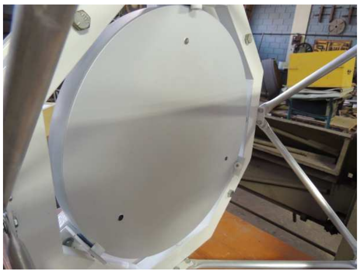


Tydex FTR measurements

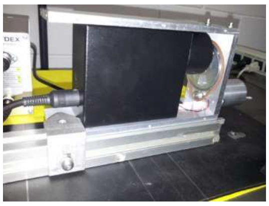
Ground-based two-frequency photometer



HATS 46 CM THz TELESCOPE

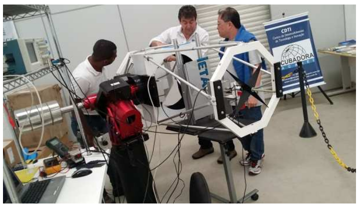


Rough surface 46 cm mirror



Golay cell detector

Chopper wheel with two band-pass filters

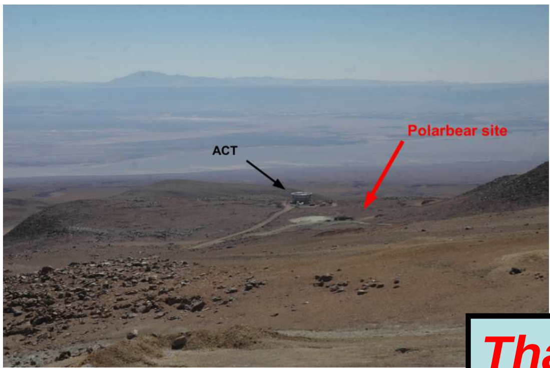


Performance tests

Paramount robotic mount

Sites: likely candidates (no decision made)

Parque Astronomico de Atacama, CONICYT, Chile, 5200m altitude



Laboratorio de Altura, Lampallado, Sierra Famatina, Argentina, 5200m altitude

Estimated burst flux detectable for PWV<1 mm

Atmosphere transmission a site with PWV < 1 mm at zenith: 0.5 at 0.85 THz and 0.15 at 1.4 THz for more than 100 days/year (i.e. optical depth $\tau \approx 0.7$ and 1.9 respectively)

Thank you!

3 σ flux detection at 45° elevation

40 SFU at 0.85 THz
140 SFU at 1.4 THz
1 SFU = 10^{-22} W m^{-2} Hz^{-1}

AFOSR Deliverables Submission Survey

Response ID:4566 Data

1.

1. Report Type

Final Report

Primary Contact E-mail
Contact email if there is a problem with the report.

pierrekau@gmail.com

Primary Contact Phone Number
Contact phone number if there is a problem with the report

+55-11-2114-8331

Organization / Institution name

Instituto Presbiteriano Mackenzie

Grant/Contract Title
The full title of the funded effort.

SOLAR EMISSIONS FROM GHz TO SUB-THz FREQUENCIES

Grant/Contract Number
AFOSR assigned control number. It must begin with "FA9550" or "F49620" or "FA2386".

FA9550-12-1-0042

Principal Investigator Name
The full name of the principal investigator on the grant or contract.

Pierre Kaufmann

Program Manager
The AFOSR Program Manager currently assigned to the award

James M. Fillerup

Reporting Period Start Date

02/14/2012

Reporting Period End Date

02/14/2015

Abstract

The resources represented an essential support to unprecedented simultaneous solar observations with the 45 and 90 GHz polarimeters, the 0.2 and 0.4 THz multiple beam solar telescope (SST), and the 30 THz microbolometer array detector (10 µm band), installed and operated at El Leoncito, Argentina Andes. Another 30 THz telescope was recently installed at São Paulo. New discoveries arose from these observations, compared to data obtained at other energy ranges, radio, visible, UV, soft and hard X-rays. Detailed spectral properties were found in the GHz to sub-THz range of frequencies; it has been discovered the importance sub-THz pulsations occurring in association to the CME launch time long before a very large flare. Possible similarities between solar flare particle accelerators to laboratory high energy accelerators have been proposed. A new plasma oscillating mechanism has been proposed for the sub-second pulses repetition rates proportionality to the mean fluxes observed in a strong impulsive sub-THz burst. The program led to the discovery of new intense 30 THz impulsive burst

correlated to white-light flare, hard X-rays, H$_{\neg\lambda}$, UV and other radio emissions. The grant provided helpful complementary research and development for the completion of next generation of solar flare THz detectors, including the integration and final tests of the 3 and 7 THz solar flare photometers SOLAR-T space experiment, and the ground-based 0.85 and 1.7 THz telescope. Ten papers published and three submitted.

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Completed_AFOSR Grant FA9550 Final Report.pdf

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Archival Publications (published) during reporting period:

-Kaufmann, P. "Observations of solar flares from GHz to THz frequencies". Astrophysical and Space Science, 30, 61-71, 2012.

-Kaufmann, P.; Holman, G.D.; Su, Y.; Giménez de Castro, C.G.; Correia, E.; Fernandes, L.O.T.; Souza, R.V.; Marun, A.; Pereyra, P. "Unusual emissions at various energies prior to the impulsive phase of the large solar flare and coronal mass ejection of 4 November 2003". Solar Physics, 279, 465-475, 2012.

Kaufmann, P.; Abrantes, A.; Bortolucci, E.C.; Correia, E.; Diniz, J.A.; Gernandez, G.; Fernandes, L.O.T.; Giménez de Castro, C.G.; Godoy, R.; Hurford, G.; Kudaka, A.S.; Lin, R.P.; Machado, N.; Makhmutov, V.S.; Marcon, R.; Marun, A.; Nicolaev, V.A.; Pereyra, P.; Raulin, J.-P.; da Silva, C.M.; Shih, A.; Stozkhov, Y.I.; Swart, J.W.; Timofeevsky, A.V.; Valio, A.; Villela, T.; zakia, M.B. "SOLAR-T: Terahertz photometers to observe slar flare emission on stratospheric ballon flights". Proc. SPIE 8442, Space Telescopes and Instrumentation 2012: Optical, Infrared, and MIlimeter Wave, 84424L1-84424L-9 (September 21, 2012). DOI: 10.1117/12.926072.

-Kaufmann, P.; White, S.M.; Freeland, S.L.; Marcon, R.; Fernandes, L.O.T.; Kudaka, A.S.; Souza, R.V.; Aballay, J.L.; Fernandez, G.; Godoy, R.; Marun, A.; Valio, A.; Raulin, J.-P.; Giménez de Castro, C.G. "A bright impulsive solar burst detected at 30 THz". Astrophysical Journal, 768, 134-143, 2013.

-Valio, A.; Kaufmann, A.; Giménez de Castro, C.G.; Raulin, J.-P.; Fernandes, L.O>T.; Marun, A. "POlarization Emission of Millimeter Activity at the Sun (POEMAS): new circular polarization solar telescopes at two millimeter wavelength rangers". Solar Physics, 283, 651-665, 2013.

Kaufmann, P.; Fernandes, L.O.T.; Kudaka, A.S.; Marcon, R.; Bortolucci, E.C.; Machado, N.; Abrantes, A.; Nicolaev, V.; Timofeevsky, A.; Marun, A.. "The performance of THz Photometers for solar flare observations from space". In: IMOC 2013 – SBMO/IEEE MTT-S International Microwave Optoelectronics Conference, Rio de Janeiro, August, 4-7, 2013. IEEEXplore 978-1-4799-1397, 2013.

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Changes in research objectives (if any):

Change in AFOSR Program Manager, if any:

Extensions granted or milestones slipped, if any:

AFOSR LRIR Number

LRIR Title

Reporting Period

Laboratory Task Manager

Program Officer

Research Objectives

Technical Summary

Funding Summary by Cost Category (by FY, $K)

	Starting FY	FY+1	FY+2
Salary			
Equipment/Facilities			
Supplies			
Total			

Report Document

Report Document - Text Analysis

Report Document - Text Analysis

Appendix Documents

2. Thank You

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